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Diesel Technology

Initial Print Date: 05/12 Revision Date:

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Diesel Technology

Model: All with Diesel Engine

Production: From Start of Production

OBJECTIVES

After completion of this module you will be able to:

- Understand fundamental diesel principles
- Understand the fundamental differences between gasoline and diesel engines
- Understand the required service procedures on diesel engines
- Understand diesel fuel injection and engine management systems
- Understand diesel exhaust emissions and emission control systems

BMW Diesel Technology

For the first time since 1986, BMW will have a "Diesel powered" vehicle in U.S. market. The previous diesel engine in use was the M21D24. The M21 was only available in the 524td (E28).

This engine featured state of the art technology which included turbocharging and the latest Bosch diesel fuel injection. At the time, the M21 was considered to be one of the best performing turbo diesel engines in the world.

However, diesel engines were not widely accepted in the U.S. market. This was due to the relatively cheap prices of gasoline and the negative perceptions associated with diesel engines.

Most of the available diesel engines available in the market at the time were not very appealing to the average customer. Engine noise, fuel and exhaust odors along with soot emissions contributed to a negative image of diesel engines. Also, diesel engines were somewhat sluggish as compared to their gasoline fueled counterparts.

One of the positive attributes of diesel engines was fuel economy and overall efficiency. This was one area in which the diesel engine excelled.

Even with all of the positive aspects of diesel ownership evident, most customers did not widely embrace the diesel experience. As a result, the 524td was discontinued in 1986.

However, since 1986, BMW continued to refine and develop diesel engines for other markets. The high price of available fuel in other countries drove customers to diesels at a higher rate than in the U.S. market.

To meet the demand for diesel engines, BMW improved on the 6-cylinder diesel engine. In addition to the 6-cylinder, 4 and 8 cylinder diesels were developed for other markets.

Over the last 20 years, BMW has continued to improve on the diesel engine and reduce the "undesirable" aspects of diesel ownership. Power output has been increased, while reducing noise and emissions. In European markets, diesel vehicles now account for more than 50% of newly registered vehicles. Sales of BMW diesel vehicles account for more than 60% of new vehicle purchases in the European markets.

In the fall of 2008, BMW will re-introduce diesel vehicles to the US market in the form of a 6-cylinder, twin turbo engine featuring the latest in common rail fuel injection technology.

The new engine will be referred to as the M57TU2 TOP. The new 6-cylinder diesel engine from BMW will offer the same high level of performance that is expected from BMW drivers.

In short, the new diesel vehicles will fit well into the concept of "Efficient Dynamics". This concept ensures the highest reduction in CO_2 emissions without a compromise in performance.

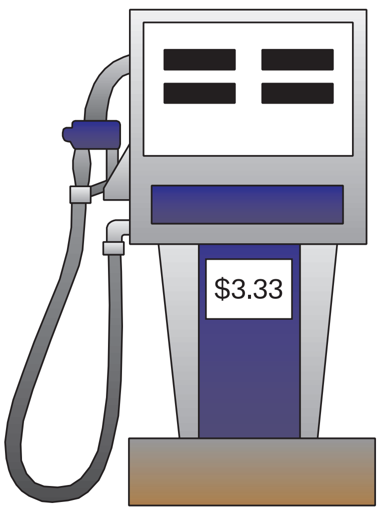
The new diesel BMW's offer two features which, together, are not usually associated with diesel engines or spoken in the same sentence - Performance and Efficiency.

Why did the diesels disappear from the US Market?

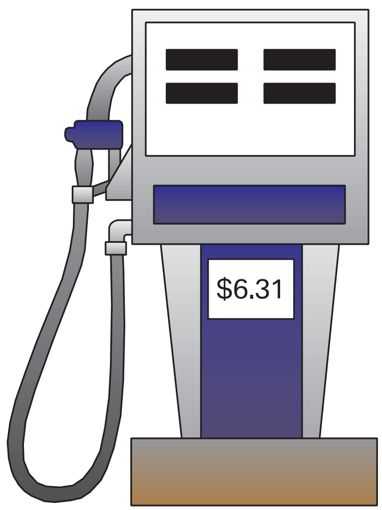
In the US market, diesel vehicles have not had much success over the last 20 years. Most of this is due to customer perception and the relatively low cost of gasoline.

Although many people feel that the price of gasoline is high in the US, other parts of the world pay much higher prices due to the additional taxes. In comparison, fuel prices in Europe are twice as high as in the US. This accounts for the difference in the overall acceptance of diesel between the US and European markets.

In the early 1980's the price of gasoline was increasing, but was not enough of a motivating factor to convert customers to diesel vehicles in sufficient numbers. Diesel engines did not offer enough of an alternative to gasoline engines because they did not perform as well. They were sluggish and did not deliver much in the way of dynamic performance.



U.S. Average Price for Diesel Fuel (winter 2010)



European Average Price for Diesel Fuel (winter 2010)

Customer Perception

More than 20 years ago, the diesel vehicles available in the US market did not have the advantages of today's technology. By the time BMW brought the 524td to the US, the diesel market had already declined due to the less than desirable aspects of some of the competitive products available at the time.

Much of the negative perception of diesel vehicles centered around the odors from the exhaust and fuel itself. Also, diesel exhaust contained a high amount of soot which contributed to the dirty image of diesel vehicles.

The combustion process in early diesel engines was abrupt and created a lot of additional engine noise as well. This noise gave the diesel passenger car more of a "truck-like" impression to potential customers.

Summary

The absence of diesel powered passenger cars in the US can be summed up in the following areas:

- Engine noise
- Exhaust odors
- Dirty, soot emissions excessive
- Fuel smell
- Low power, lack of performance, sluggish
- Cold starting performance
- High emissions of NO_X

The above mentioned issues on the diesel engine have been resolved with the advancements in engine, emissions and fuel injection technology. In the subsequent pages, the latest diesel technology will be reviewed and explained in more detail.

Why are diesels making a comeback in the US?

Given the current global concerns, BMW diesel engines are a logical choice for customers looking for economy and performance. There are other alternatively fueled vehicles on the market today, but BMW offers a true "premium" experience with the diesel engine.

Everyday, the news is filled with articles on global warming and the need for a reduction in CO_2 emissions. There are continuing discussions on the need to reduce our dependence on foreign oil and to look for alternatives.

BMW is offering alternatives in the form of Hydrogen power, future Hybrid technology and now "Diesel Power" for the Ultimate Driving Machine.

In the last 20 years, BMW has developed "cutting edge" diesel engines which have gone relatively unnoticed in the US market. This is due, primarily, to the perception of the customer.

Past negative experiences or a lack of overall diesel knowledge have kept customers from experiencing diesel technology. The lack of available diesel vehicles in the US has only served to keep interest at a minimum.

Today, more and more customers are becoming aware of diesels and the potential benefits of ownership. BMW offers all of these benefits with the addition of performance and the usual value that customers expect.

The new BMW engines benefit from the latest "common rail" fuel injection systems. These systems are high pressure, precision injection systems which are capable of having multiple injection events. These systems contribute to the increased performance and reduction of emissions.

As compared to the M21 engine from 1983, the latest BMW diesel vehicles have improved in the following areas:

- Engine noise has been reduced by engine design and fuel injection strategy. Additional engine soundproofing also contributes to the reduction in noise.
- Particulate emissions have also been reduced by 99% as compared to the M21 engine. This was accomplished by injection strategy and by the new diesel particulate filter (DPF).
- Fuel consumption has been reduced by 20%.
- Torque output has been increased by 160% through the use of the innovative twin-turbocharger design.
- Horsepower has been increased by more than 135%.
- NO_X is further reduced by the diesel oxidation catalyst, EGR valve and by the new SCR system.
- Other engine modifications also contribute greatly to the modern BMW diesel engine.

In short, it's time to bring the diesel back.

Efficient Dynamics

Today, much of the focus from the automotive industry centers around fuel efficiency and concern for the environment through the reduction in CO_2 output. Usually, the words “efficient” and “dynamic” are not usually adjectives used to describe the same vehicle. However, this is not the case when describing vehicles from BMW.

Many of our customers are familiar with our most famous tag line “The Ultimate Driving Machine” and they won’t settle for anything less. It is a huge challenge to not only meet performance expectations, but to maintain overall efficiency and environmental responsibility.

BMW has been able to meet and exceed these goals through the latest innovations in engine technology. Systems such as VANOS, Valvetronic, lightweight engine construction and the latest in engine management have contributed to increasing performance while improving fuel economy.

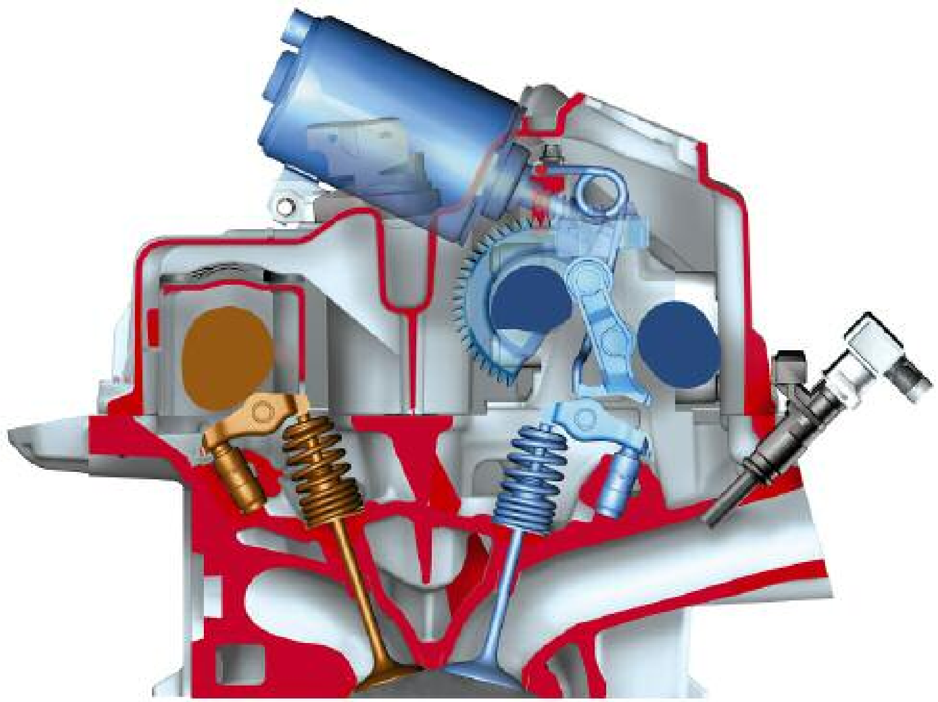
One of the first vehicles to be associated with the “Efficient Dynamics strategy was the BMW Hydrogen 7. This vehicle is also the flagship for BMW’s “Clean Energy” concepts. The new BMW Hydrogen 7-series is “bivalent” which means it can be run on both gasoline and hydrogen.

The “Hydrogen 7” has a V-12 internal combustion engine which takes advantage of one of the most plentiful and “eco-friendly” resources on Earth - Hydrogen. Using hydrogen as an automotive fuel is not an entirely new concept for BMW. These ideas have been in development by BMW since the 1970’s.

It’s important to note, that the new Hydrogen 7 is not only a concept vehicle, but is a production vehicle which is currently for sale. Although it is not currently available in the US, is being tested here and will be for sale in other markets.

BMW's dedication to Efficient Dynamics does not rest on a single vehicle, but rather is evident on many other new products and technologies.

For example, BMW gasoline engines have had many fuel saving innovations for many years. Recently, Valvetronic technology has allowed BMW vehicles to gain "best-in-class" fuel economy across the model line.



Some of the other engine innovations include high-precision direct fuel injection for gasoline engines. The HPI system allows the N54 engine to maintain maximum performance and astounding fuel economy in a 300 hp engine.

To complement all of the engine technology currently in use, BMW will be adding diesel powered BMW's to the model line by the end of 2008. Besides the obvious fuel saving advantages of diesel engines, there are many performance related aspects of this new technology.

The new 335d for the U.S. market is expected to accelerate from 0-62 mph in 6.2 seconds while achieving a fuel economy of 23/36 mpg (city/highway provisional data). The same engine in the X5 can accelerate to 62 mph in 7.2 seconds while offering fuel economy figures of 19/26 mpg (city/highway provisional data).

With its carbon emissions down 10% - 20% from comparable gasoline vehicles, and near-elimination of both smoke and NOx emissions, BMW Advanced Diesels will be every bit as clean as CARB-legal gasoline engines when they are introduced in the US in 2008.

Both diesel and gasoline engines from BMW have taken home the prestigious "International Engine of the Year Award" several times. Now, one of these award-winning diesel engines will be available in 2009 models.

New Diesel Engine

Some of the features on the M57TU2 TOP include:

- A horsepower rating of 265 hp
- 425 lb-ft (580 Nm) of torque
- 3rd Generation common rail fuel injection (1600 bar) with Direct Injection
- Piezo-electric injectors
- Two-stage turbocharging with intercooler
- Lightweight aluminum alloy crankcase
- Particulate filter (DPF)
- EGR system with EGR cooler
- Diesel Oxidation Catalyst
- Digital Diesel Electronic (DDE)
- Selective Catalytic Reduction (SCR) System

In addition to the features listed above, the new 6-cylinder diesel includes fuel heating system and a new “fast start” glow plug system to ensure optimum cold weather starting.

Note: In accordance with the current engine numbering system, the M57TU2 TOP engine will be known officially as the M57D30T2.

Engine Specifications

M57TU2 TOP/M57D30T2	
Number of Cylinders	6
Bore	84
Stroke	90
Displacement	2993 cm3
Compression Ratio	16.5:1
Compression pressure	> 12 bar
Maximum RPM	5250
Maximum continuous RPM	4400

U.S. Diesel Specifications

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.

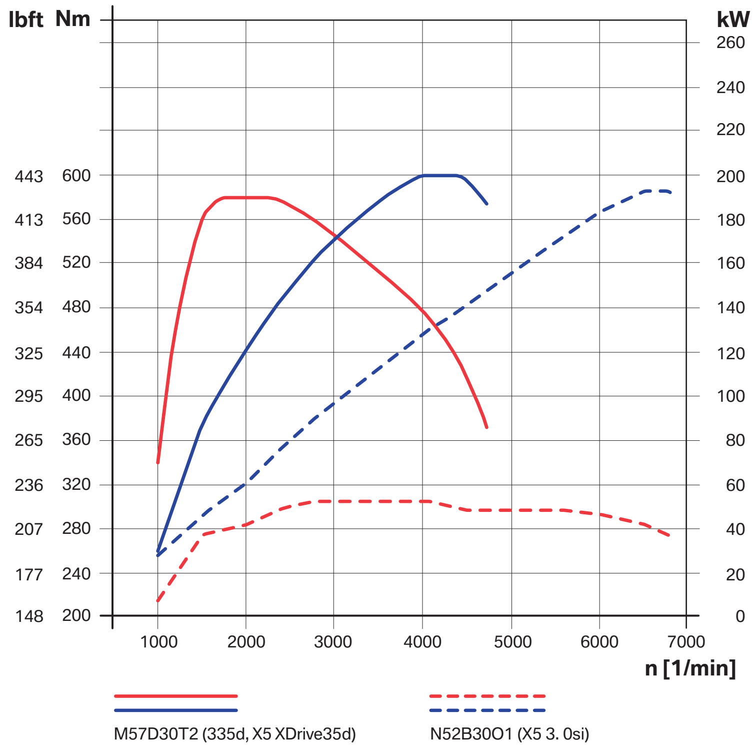
The following pages contain a comparison of the new BMW diesel engine technology to the current BMW gasoline engine technology.

Technical Data Comparison

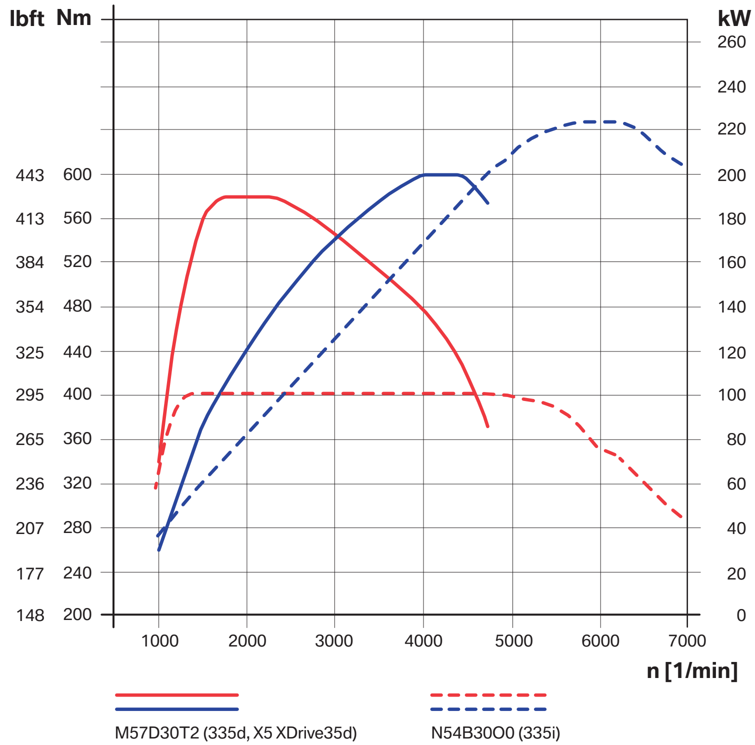
Description	Units of Measurement	N52B3O01	N54B30O0	N62B48O1	M57D30T2 (US)
Engine type		R6	R6	V-8	R6
Displacement	(cm3)	2996	2979	4799	2993
Firing order		1-5-3-6-2-4	1-5-3-6-2-4	1-5-4-8-6-3-7-2	1-5-3-6-2-4
Stroke	mm	88	88.9	88.3	90
Bore	mm	85	84	93	84
Power output @ rpm	hp @ rpm	260@6600	300 @ 5800	360 @ 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.

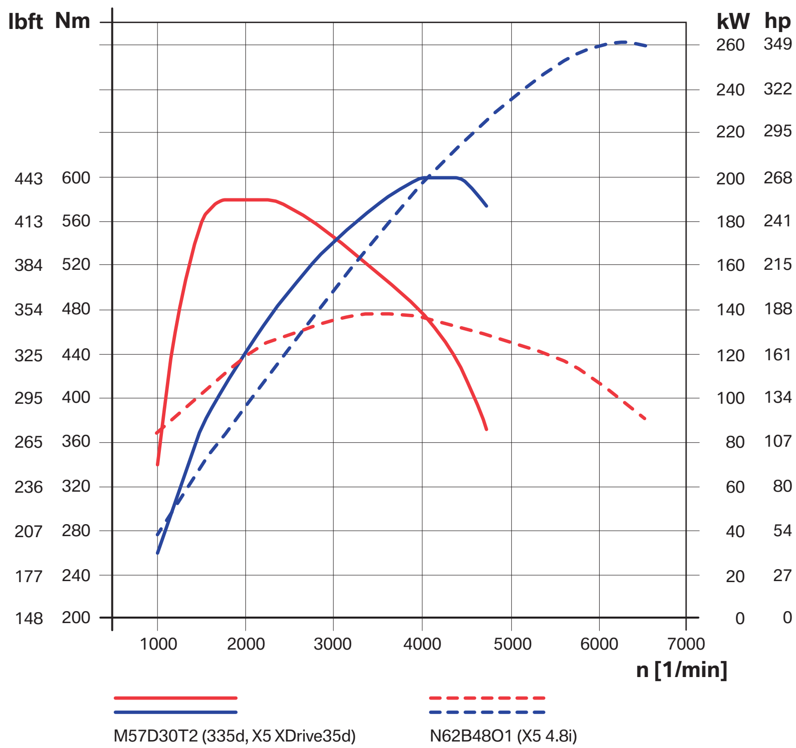
Most notably, the diesel has the advantage in the torque output. The above comparison shows a comparison between the N52 engine, which is a naturally aspirated 3-liter gasoline engine.

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.

Diesel vs. N62



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.

NOTES PAGE

Diesel Fundamental Principles

First and foremost, a diesel engine operates on the “compression ignition” principle. A compression ignition engine begins the combustion cycle without the need for an external ignition system.

What makes a diesel engine attractive to potential customers is that it is much more efficient than a gasoline engine. This is due to several factors:

- Diesel engines run at a much higher compression ratio
- The energy density of diesel fuel is much higher than an equivalent amount of gasoline
- Overall, diesel engines are more thermally efficient than gasoline engines
- Diesel engines are run very lean (with excess air)
- Diesel engines operate with the throttle in the open position which reduces pumping losses

In order to ignite fuel without a spark, the compression ratio must be relatively high. The compression ratio on most gasoline engines ranges from 8:1 up to as high as 12:1. On the other hand, compression ratios on diesel engines range from 16:1 up to about 22:1 for most passenger car engines.

A direct benefit of a higher compression ratio is increased thermal efficiency. In comparison to a gasoline engine of comparable displacement, modern diesel engines generate more cylinder pressure during the compression phase. The average “mean cylinder pressure” value of a turbocharged diesel engine is from 8 to 22 bar, while a comparable turbocharged gasoline engine is only about 11 to 15 bar.

A higher mean pressure value in combination with the higher energy density of diesel fuel translates to more pressure during combustion. This higher combustion pressure is responsible for much higher output torque. This additional torque is available at a relatively low RPM as compared to a gasoline engine.

The load control of a diesel engine is not carried out by regulating the amount of air as on a gasoline engine. Rather, the diesel engine is “throttled” by the amount of fuel injected. This type of load control means that the throttle butterfly is mostly open during all engine phases.

Since the throttle is always open, there is always more than enough oxygen available to burn all of the fuel injected. This allows then engine to operate in a very lean state which also contributes to increased efficiency of the diesel engine.

In comparison, gasoline engines must run at a lambda value as close to 1 as possible. A diesel engine can operate at lambda level of 1 to 2 under load and up to 10 when at idle or under low load conditions.

An added benefit of having the throttle open during most phases of engine operation is the reduction of pumping losses. This has the same beneficial effect that Valvetronic has on a gasoline engine.

In summary, early diesel engine designs were already much more efficient than the prevailing gasoline engine technology. However, fairly recent developments in engine and fuel injection technology have contributed to major advances in the success of the diesel engine.

In particular, modern BMW “Performance Diesel” engines provide the added bonus of economy ***and*** performance. The already proven diesel engine has been enhanced and optimized to fulfill the brand promise of “The Ultimate Driving Machine”.

Diesel Engine to Gasoline Engine Comparison

In order for the diesel engine to start it's combustion cycle, fuel must be ignited by the heat of compression. The fuel used must be able to spontaneously ignite (without the help of a spark from an external ignition source). So, the fuel required for a diesel engine must have special properties to be compatible with proper engine operation. The best way to illustrate this is to compare both engines and the fuel used.

The following is a comparison of a gasoline engine as compared to a diesel engine:

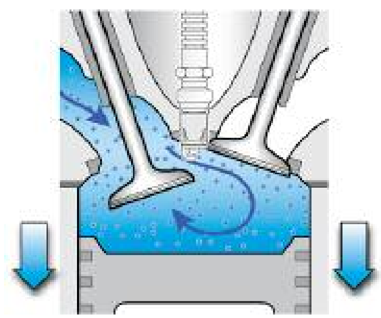
Specification	Gasoline Engine (Otto)	Diesel Engine
Ignition Type	Spark Ignition	Compression Ignition
Compression Ratio	Between 8:1 and 12:1	Between 16:1 and 22:1
Efficiency	25-30%	36-45%
Maximum Engine Speed	7000-8250 RPM	up to 5250 RPM
Exhaust Temperature (under full load)	700-1200 Degrees Celsius	300-900 Degree Celsius
Fuel Type	Gasoline **(Octane rating = resistance to knock)**	Diesel **(Cetane rating = ability to ignite)**
Fuel Density	0.74 - 0.77	0.82 - 0.85
Flash Point	-47 Degrees Celsius (-52.6 Degrees Fahrenheit)	55 Degrees Celsius (131 Degrees Fahrenheit)
Ignition Temperature	550 Degrees Celsius (1022 Degrees Fahrenheit)	350 Degrees Celsius (662 Degrees Fahrenheit)

Combustion Cycle Comparison

Much like a gasoline engine, the diesel engine uses the 4-stroke cycle. The familiar sequence of; Intake > Compression > Power and Exhaust is much the same on a diesel engine. The difference is mostly in how the fuel is ignited and when fuel is introduced into the combustion chamber.

The other area in which diesel engines differ is in the compression ratio. The typical gasoline engine has compression ratios of between 8:1 up to about 12:1. On the other hand, diesel engines have a typical compression ratio of between 16:1 and 22:1. The higher compression ratio is required to sufficiently compress the air charge and raise the temperature to the ignition point.

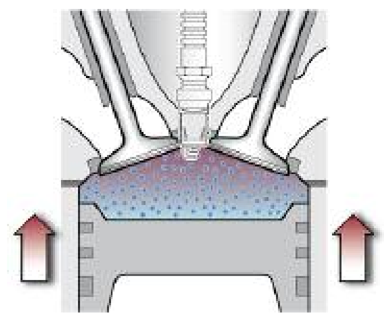
The illustrations below show the sequence of the combustion cycle on a conventional ***gasoline*** engine with “manifold injection”.



Intake Stroke
Gasoline Engine
A low pressure area is created as the piston moves downward in the cylinder bore.

As the intake valve opens, a mixture of air and fuel is allowed to enter the cylinder to fill the void created by the low pressure area.

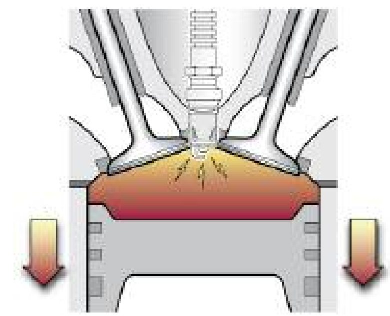
Note:
A gasoline direct injection engine would only induct air during this period.



Compression Stroke
Gasoline Engine
As the piston moves up in the cylinder, both valves are closed.

The mixture of air and fuel is compressed to a specific ratio.

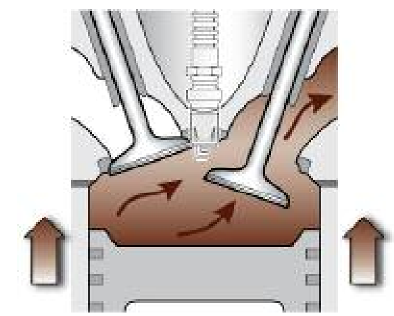
Note:
A gasoline direct injection engine would only compress air during this period.



Power Stroke
Gasoline Engine
The compressed air and fuel mixture is ignited by a spark from the ignition system.

The piston is forced down in the cylinder by the expanding gases. This creates the necessary force to drive the crankshaft.

Note:
A gasoline direct injection engine would inject fuel and ignite it with a spark during this period.

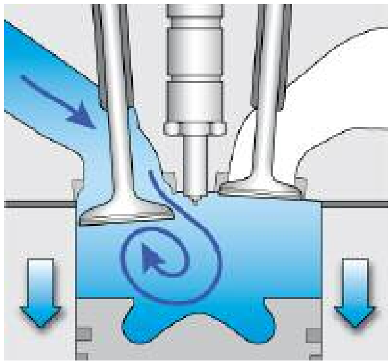


Exhaust Stroke
Gasoline Engine
The exhaust valve opens as the piston moves up in the cylinder which expels the spent gases formed during the combustion process.

Note:
A gasoline direct injection engine would operate the same during this period.

Diesel Combustion Cycle

In the example above, the combustion cycle on the gasoline engine was discussed. In contrast, the sequence below outlines the combustion cycle on the diesel engine. This will help in the understanding of the diesel/gasoline engine comparison.

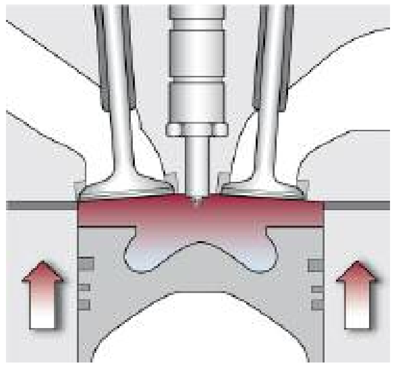


Intake Stroke
Diesel Engine

A low pressure area is created as the piston moves downward in the cylinder bore.

As the intake valve opens, air is allowed to enter the cylinder to fill the void created by the low pressure area.

Note:
The recess in the piston and the design of the intake manifold assist in creating a “swirl effect” for the incoming air.

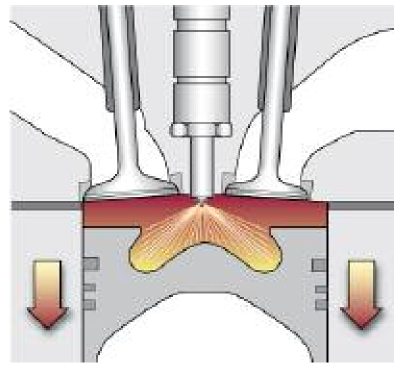


Compression Stroke
Diesel Engine

As the piston moves up in the cylinder, both valves are closed.

The air is compressed to a high ratio and therefore heated to a high temperature in preparation for the incoming fuel.

Note:
Only air is compressed during this period.



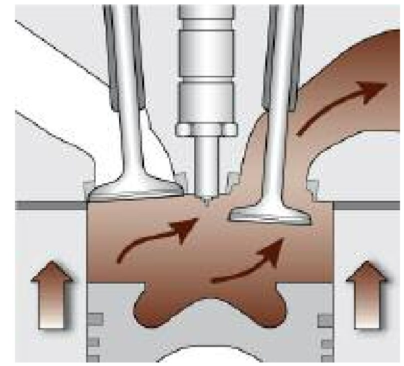
Power Stroke
Diesel Engine

Just before the piston reaches TDC, fuel is injected at high pressure directly into the combustion chamber.

The fuel spontaneously ignites and pushes the piston down in the cylinder.

This creates the necessary force to drive the crankshaft.

Note:
Fuel is injected for a longer time during this period. This feature contributes to the additional torque generated by a diesel engine.



Exhaust Stroke
Diesel Engine

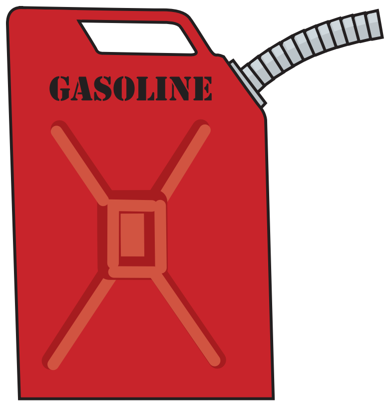
The exhaust valve opens as the piston moves up in the cylinder which expels the spent gases formed during the combustion process.

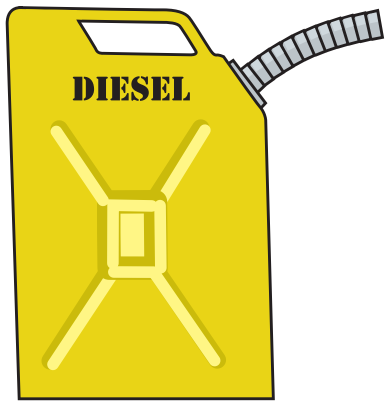
Note:
Due to the higher thermal efficiency of a diesel engine, the exhaust temperature is lower as compared to a gasoline engine.

Diesel Fuel Properties

Before discussing diesel fuel injection or fuel systems, it is necessary to explain the properties of diesel fuel and how it differs from gasoline. Although both fuels are distilled from crude oil, they each have their own uses and applications and should never be interchanged.

Gasoline
The BTU value for gasoline is approximately 125,000 BTU per gallon





Diesel Fuel
The BTU value for diesel fuel is approximately 147,000 BTU per gallon

Diesel Fuel

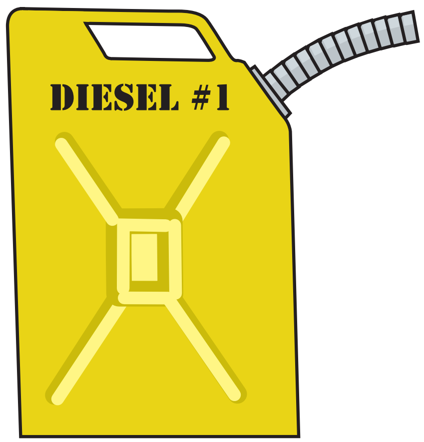
As with gasoline, diesel fuel is a by-product of the distillation of crude oil. Diesel fuel is a hydrocarbon with different chemical properties than gasoline. Diesel fuel is part of the "middle distillates" derived from crude oil. This means that diesel fuel is "heavier" than gasoline but "lighter" than oil used for lubrication (i.e. motor oil). There are numerous advantages to diesel engines, due to the properties of the fuel used. Some of these advantages include:

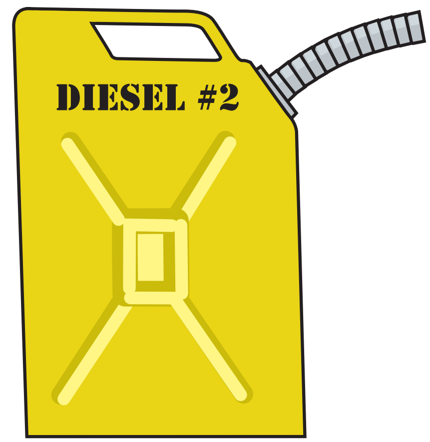
- Thermal Efficiency - Diesel fuel produces more power than gasoline. In other words, Diesel fuel has a higher energy content. One gallon of gasoline contains about 125,000 BTU of heat energy. In comparison, one gallon of diesel fuel contains about 147,000 BTU. This advantage in thermal efficiency, adds up to increased fuel economy.
- Increased Durability - Due to the lubricant properties of diesel fuel, piston ring life is greatly increased. Gasoline has more of a detergent quality which tends to decrease piston ring life. It is not uncommon for light duty diesel passenger vehicles to have an engine which lasts more than 200,000 miles.
- Improved Emissions - Diesel fuel contains more carbon atoms per gallon and therefore will emit more CO_2 per gallon. However, the increased efficiency of a diesel engine allows for an overall reduction in CO_2 (per mile). In comparison, diesel engines are run leaner (with excess air), and produce lower levels of HC, CO and CO_2. The lower volatility of diesel fuel, allows for less evaporative emissions overall. The only area where diesel engines do not excel are in NO_X and Particulate Matter (PM). But, new technology allows diesel engines to comply with prevailing emission standards.

Diesel Fuel Types

The term “diesel fuel” is a generic term, it refers to any fuel for a compression ignition engine. As mentioned before diesel fuel is derived from the “middle distillates” of crude oil. There are other similar products in this range such as kerosene, jet fuel and home heating oil just to name a few. However, each of these products is designed for a specific application. In theory, these additional products may work in a diesel application, but it is not recommended. Diesel fuel has specific properties which are designed to offer the best reliability, the best fuel economy and the highest compatibility with engine and fuel system components.

As far as passenger cars are concerned, there are two main types of diesel fuel. These are Grade 1 and Grade 2. Usually referred to as Diesel Fuel #1 and Diesel Fuel #2. Mostly, Grade 2 is used for passenger cars and is the most widely available.





The difference between diesel fuel #1 and #2 is addressed in the following:

- Diesel #1 has about 95% of the BTU content as #2 diesel.
- Diesel #1 has a lower viscosity and provides less lubrication to the fuel system components such as the fuel pump and injectors.
- Diesel #1 has a lower waxing point than #2 and will perform better a low ambient temperatures.
- Diesel #1 usually has a slightly lower Cetane rating than #2, but is above the minimum rating of 40.

Winter Fuel

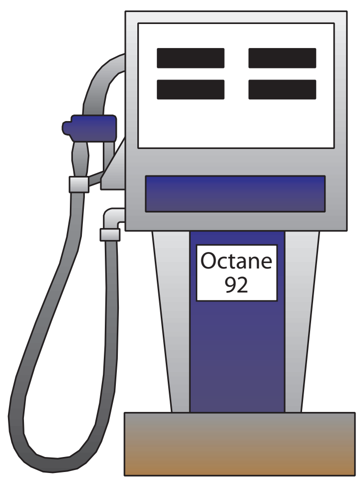
Petroleum companies generally offer “winter” and “summer” grade fuels on a seasonal basis. Winter fuel is created by blending a specific amount of #1 Diesel fuel to a quantity of #2 Diesel fuel. This lowers the freezing (waxing) point to prevent fuel filters from clogging or the fuel from causing any cold weather starting problems.

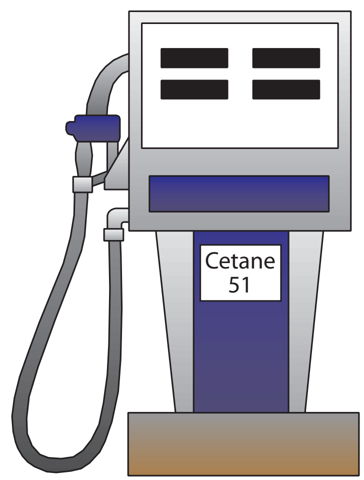
In the heavy trucking industry, there have been some other methods to “winterize” diesel fuel. Some of these methods include adding kerosene or other fuels to improve cold weather starting ability. However, this is ***not*** recommended for passenger cars and may, in fact, cause engine or fuel system damage. Therefore, the only recommended method is to purchase diesel fuel from a reputable retailer

Cetane Rating

When rating gasoline, the term “octane” has been used to refer to the anti-knock quality of a fuel. Octane rating refers to the resistance to prematurely ignite under pressure. When the octane number is higher, the fuel is more resistant to pre-ignition and therefore engine knock. Therefore, a higher octane number is more desirable. For example, today’s octane ratings range from 87 to 93 for commercially available passenger cars.

In Diesel applications, the term “cetane” is used to rate fuel quality. However, the desired fuel quality goals are different for diesel. The cetane rating of diesel fuel refers rather to the “ease of ignition”. After all, a diesel engine is a “compression ignition” engine and therefore, it is more important for diesel fuel to combust easily under pressure. Cetane ratings are in a range of 0 to 100. 100 is an indicator of pure Cetane (n-hexadecane), or the most combustible. Most commercially available diesel fuel has a cetane rating of about 45. A rating of 40 is usually considered to be the absolute minimum rating for today’s passenger vehicles. Newer BMW vehicles will require a Cetane rating of 51. Always check the owner’s manual to see the minimum fuel requirements and the recommended cetane number. A higher cetane rating also contributes to better starting especially in cold weather. When possible, it is always better to use fuel with a higher cetane rating. Also, a higher cetane number equates to a reduction in NO_X and particulate matter emissions.



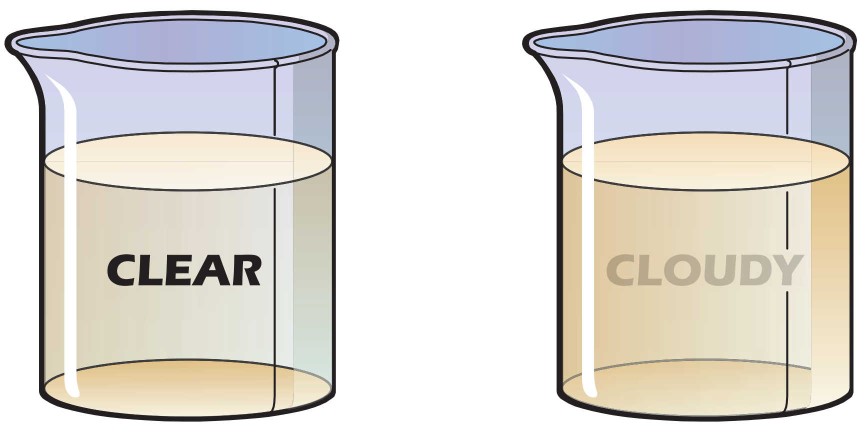


Cold Weather Properties

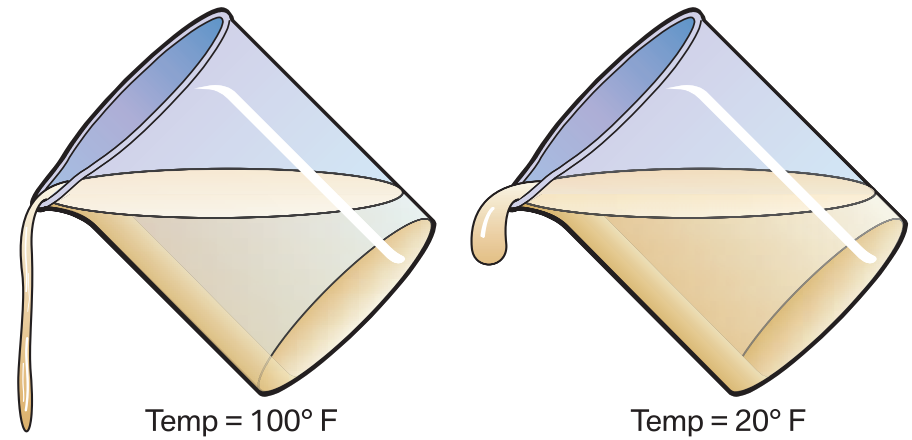
As with all fuels distilled from crude oil, there is a presence of paraffin wax. This wax
content depends of the type of fuel. Since diesel fuel is a "middle distillate" of crude oil, there are more paraffin compounds present. These waxy compounds flow well at normal ambient temperatures. However, in cold operating temperatures, these compounds begin to solidify and can restrict fuel flow resulting in difficult starting.

Cloud Point

The cloud point is the temperature at which the fuel will start to solidify. The paraffin compounds begin to crystallize and the fuel becomes cloudy. The ability of the fuel to flow is impeded, but is still able to move through the system. The cloud point of #2 Diesel fuel is about 20 degrees Fahrenheit (-7 degrees C).



Temp = 100° F   Temp = 30° F

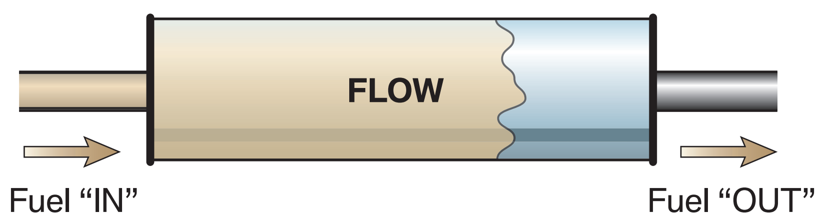


Temp = 100° F   Temp = 20° F

Pour Point

Pour point is the temperature in which the fuel will no longer flow. It is usually 6 to 10 degrees Fahrenheit below the cloud point.

Cold Filter Plugging Point (CFPP)
Diesel fuel is a hydrocarbon which contains paraffin waxes. At warm temperatures, these waxes will flow easily through the fuel system. However, at low ambient temperatures, these waxes will tend to solidify. This situation causes the fuel to start to solidify. Due to the paraffin content in middle distillate's like diesel fuel, is possible during cold temperatures for the fuel to solidify. The CFPP is about -4 degrees F (-20 degrees C).



Cold Climate Measures
Most, if not all, modern vehicles equipped with diesel engines employ measures to heat the fuel and reduce the possibility of wax formation a.k.a gel. The measures include a heated fuel filter and glow plugs. These systems will be discussed in subsequent training modules.

Diesel Fuel Additives
When diesel fuel is refined, numerous additives are used to improve the qualities of the fuel. These additives can be introduced at the refinery level or at the distribution level. One such additive is an "Anti-foaming" agent which helps when refueling the vehicle by reducing the foam buildup when the fuel is aerated.

Detergents are added to allow the diesel fuel to assist in the cleaning of engine and fuel system components. These detergent combat the possibility of sediment or "gum" buildup which can be detrimental to the fuel system. Modern high pressure diesel fuel injection systems are sensitive to any dirt or varnish buildup.

California requires the use of low aromatic diesel fuel. Additives are used in this case to lower the aromatic quality of the fuel. In the future, some other states may require the use of "low aromatic" diesel fuel.

Some additional additives include:

- Cetane number improvers
- Smoke suppressants
- Low temperature operability additives
- Biocides (to prevent growth of microbes in the fuel)
- Corrosion inhibitors
- Dyes (for identification)
- Lubricity additives

Dyes
Dyes are added to diesel fuel for identification. There are two primary reasons that fuel needs to be identified. The IRS requires diesel fuel to be identified for tax purposes and the EPA requires fuel to be identified for fuel quality (i.e sulfur content).

To comply with the tax code, fuel is usually dyed red for agricultural use. The fuel used for farm equipment is not as heavily taxed as that which is used for "over-the-road vehicles. Using "red-diesel" in a passenger car or truck is a violation of the tax code and therefore should not be used.

The so-called "red diesel" fuel is also dyed to show visible evidence of "high-sulfur"fuel.

Starting in 2007, the diesel fuel used in new cars is supposed to be "ULSD" or Ultra-low Sulfur Diesel. The EPA requires a specific quantity of red dye to be used in any fuel which is not of the ULSD variety.

The sulfur content of this fuel has been drastically reduced to help modern vehicles meet emission requirements. Therefore, "red diesel" should not be used in any "over-the-road" vehicle.

Microbes

When fuel is refined, the high temperatures achieved during this process will "sterilize" the fuel. However, after the fuel has cooled, it is possible for microorganisms to grow.

This is possible because there is usually some water present is diesel fuel which comes from condensation and during the transfer/distribution phases.

The microbes feed on the interface between the water and fuel. These colonies can thrive in the absence of light. Some microbes are also anaerobic, which means they can survive in the absence of oxygen as well.

These microbes can multiply into colonies which can become large enough to clog fuel system components. The best way to combat these organisms is to keep the fuel as clean as possible and reduce or eliminate the presence of water.

Diesel fuel distributors use biocides to attack the microbes and reduce their numbers.

Sulfur Content

Sulfur is a naturally occurring element found in crude oil. Through the refining process various sulfur compounds occur and are present in the final product. Up until 1985, not much attention was paid to the sulfur content in diesel fuel.

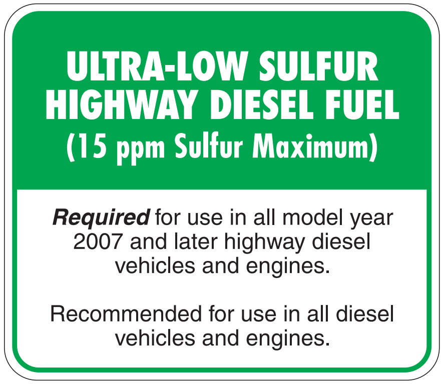
The presence of sulfur in diesel fuel contributes to unwanted soot and particulate emissions which are present in diesel exhaust. So, beginning in 1985, the EPA and CARB began with regulations on the sulfur content of diesel fuel. This led to the use of low sulfur diesel fuel.

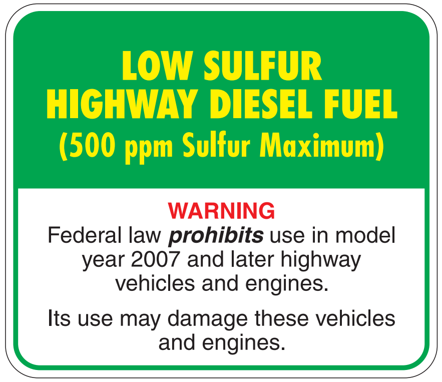
Up until 2007, diesel fuel regulations required the use of "Low Sulfur Diesel" or LSD. The sulfur content of LSD is 500 parts per million. LSD fuel was compatible with the diesel technology at that time, but there was still substantial particulate matter emissions (PM).

For the 2007 model year, the EPA has mandated the use of Ultra Low Sulfur Diesel fuel or ULSD. This new fuel represents a 97% decrease in sulfur content. The maximum sulfur content in ULSD is 15 ppm. As a comparison, this amounts to about 1 ounce of sulfur for an entire tanker truck of diesel fuel.

One of the reason that ULSD fuel is needed is to be compatible with the latest generation of "clean diesel" vehicles. These vehicles include a Diesel Particle Filter (DPF) which is used in the exhaust system to trap and reduce particulate emissions. The use of ULSD assists greatly in the reduction of particulate matter emission.

Using LSD fuel in a vehicle which requires ULSD can damage the DPF and result in unwanted emission levels and unnecessary component damage. So, only ULSD fuel should be used especially on vehicles equipped with a DPF.





No longer available

When refueling a vehicle which requires ULSD, be sure to check the label located on the pump. This label should be in a conspicuous location. Above, is an example of the correct label for ULSD fuel on the left. The right is an example of LSD fuel (pre-2007).

By December of 2010, all gas stations are required to be in compliance with the ULSD requirements. As of 12/10, LSD fuel will no longer be available for highway use.

Vehicles which require LSD will be able to run on ULSD without any modifications. The ULSD fuel meets all lubricity requirements for vehicles made prior to 2007.

Lubricity

One of the qualities of diesel fuel is that is provides the needed lubrication for engine and fuel system components. By nature, diesel fuel is very oily and is more viscous (thicker) than gasoline. This is why diesel fuel is sometimes referred to as fuel oil.

Some components such as the injectors and high pressure pump will not function properly without lubrication. The presence of sulfur and sulfur compounds contribute to the overall lubrication qualities of the fuel.

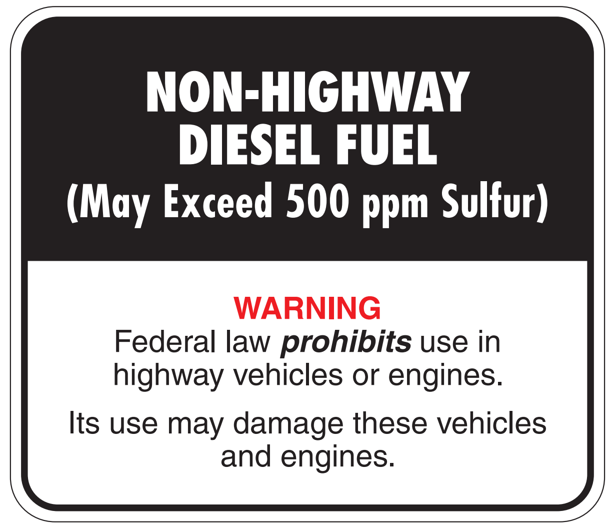
With LSD fuel and the new ULSD, additives are used to enhance the lubricity of the fuel. So, older vehicles will be able to use ULSD without any modifications or concerns.

Grades

ULSD fuel will be available for both Diesel #1 and Diesel #2 grades.

Off Road Use

Currently, ULSD is not required for “off-highway” use. This includes agricultural equipment, locomotive and marine use. ULSD will not be required on these applications until 2010. Until that time, LSD fuel with 500 ppm sulfur will be available (see label below).



Flash Point and Auto-ignition

The flash point of a fuel represents the lowest temperature as to which it will be able to be ignited. Gasoline and diesel fuel have different properties, and therefore different flash points.

A gasoline engine or “spark ignition” engine needs a fuel which can be ignited by a spark, but will not “self-ignite” under the heat of compression. Gasoline which has a lower flash point that diesel fuel can be ignited easier with a outside source of ignition i.e. spark or open flame. The flash point of gasoline is at about -43 degrees Celsius (-45 F) which works well in a gasoline engine, but not in a diesel. A low flash point also makes gasoline more dangerous to handle.

Gasoline, however, has a higher auto-ignition temperature which helps the fuel resist self ignition in a gasoline engine. The auto-ignition temperature of gasoline is about 256 degrees C or 475 degrees Fahrenheit.

Diesel fuel has a much higher flash point of about 52 degrees C or above. This flash point varies between fuel types i.e. #1 or #2 diesel. In contrast, the auto-ignition temperature of diesel fuel is 210 degrees C or 410 degrees Fahrenheit. This particular quality of diesel fuel is compatible with a “compression ignition” engine.

Fuel Mixing

Among the other attributes of automotive fuels, flash point and auto-ignition temperature are perhaps the primary reasons why these fuels should never be mixed. Mixing gasoline into diesel fuel will lower the flash point rendering the fuel unsafe to handle. Also, the flash point and auto-ignition temperature of gasoline would adversely affect a diesel engine, even to the extent of engine damage.

With regards to a diesel engine, it is also important to be aware that gasoline has little in the way of lubrication properties sufficient for diesel fuel system components. This is of a particular concern to the high pressure fuel pump which can be damaged when gasoline is introduced into the fuel system.

The inverse is also true when fueling a gasoline powered vehicle incorrectly with diesel fuel. Irreparable engine damage can result costing thousands of dollars.

Diesel Oil

In addition to the fuel used to run a diesel engine, there are also considerations which must be taken into account regarding the lubricating oil in a diesel engine. Since the combustion chamber temperature of a diesel engine is higher than a gasoline engine, the oil temperature is also higher. So, engine oils used in diesel engines must be able to withstand the higher temperature demand.

In addition to the already high service demand on diesel engine oil, BMW diesel engines are turbocharged which further increases the demands on the engine oil.

In the U.S., lubricating oils are rated through the American Petroleum Institute (API). Engines, whether gasoline or diesel powered, each have their own classification as far as lubricating oils are concerned.

The lubricating oil used in current diesel engines must conform with regulations regarding sulfur content.

For the correct motor oil for diesel engines, always refer to the proper owner's manual or the "Operating Fluids Specifications Manual".

Castrol SAE 5W-30 TXT LL-04 Synthetic

Part number 07 51 0 037 195

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Engine Mechanical

In the early stages of diesel engine development, most if not all were used in stationary applications for power generation, pumping or to provide motive power for large ships. The engines were heavy and impractical for use in ground transportation. During the early part of the 20th century, diesels were gradually downsized and improved to make mobile applications possible.

Although diesel engines were always more mechanically and thermally efficient than gasoline engines, the early designs were heavy and took up a lot of space. So, much of the early development of “mobile” diesel engines centered around heavy trucks.

By the time diesel engines were adapted to automobiles in the 1930’s, the engine size was reduced and lightened considerably. But, this weight reduction was still not enough to make the diesel engine a great performer.

Most of the early automotive diesel engines were using cast iron cylinder blocks and cylinder heads. The fuel efficiency that was gained from the use of diesel engines was somewhat offset by the heavier engine designs. As a result, performance suffered and the overall opinion of diesel engines was that they were slow and sluggish.

BMW did not start to develop a diesel engine until the late 1970’s when fuel prices were on the incline and the environment was becoming a concern. The sluggish performance of early diesel engines did not fit into the “sporty” driving style of BMW customers. Over the years, other vehicle manufacturers designed diesel engines and marketed diesel powered vehicles, but most were not considered sporty or high-performance in any way.

Therefore, BMW needed to develop a diesel engine that was a “real” alternative to the gasoline engine. Anything less would not fit into the image of the “Ultimate Driving Machine”.

The development of the M21 engine was preceded by an experimental diesel engine known internally as the M105 which was initially developed in 1978. The production version of the first BMW diesel engine (M21) would be introduced in 1983.

Early BMW diesel engines utilized cast iron for crankcase construction. This was due to the high combustion chamber pressures generated in the diesel combustion cycle.

The latest diesel engines from BMW take advantage of advancements in aluminum casting technology. This allows the current and future diesel engines to be lighter without compromising strength. Some of the other areas which are different in diesel engines extend to many of the internal engine components.

These areas include pistons, crankshaft, connecting rods, cylinder head and valvetrain. These components are generally stronger and are constructed of different materials as compared to their counterparts on gasoline engines.

Engine Crankcase Construction Comparison

In order to be compatible with the higher combustion pressures and torque output in a diesel engine, the crankcase must be stronger and more robust than a gasoline engine. Early BMW diesel engines used a cast iron crankcase, but current advances in aluminum casting technology have allowed the use of lightweight alloy cylinder blocks for diesel applications. The new M57 aluminum crankcase saves 20 kg over the cast iron version.

One of the first engines to use this technology was the M57TU2 (6-cylinder) and later the M67TU (8-cylinder). Both of these engines were introduced for the 2005 model year (in non-US markets). The aluminum crankcase has externally cast ribs in addition to stronger aluminum alloy to ensure optimum block rigidity.

The graphics shown below are an illustration of the differences between the crankcase on a diesel engine as compared to a crankcase used on a gasoline engine. Note the additional cast ribs on the diesel crankcase which contributes to the needed rigidity. Block rigidity is further optimized by the closed deck design as compared to the open deck on the N54/N52 engine.

Crankcase for diesel engine (M57TU2 aluminum)

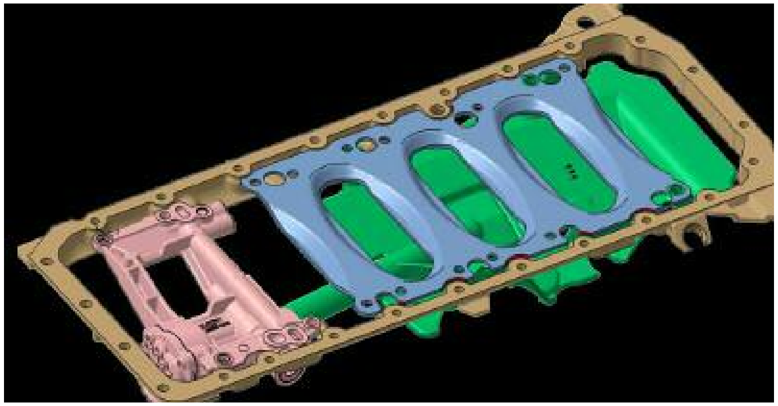
Crankcase for gasoline engine (N54 aluminum)

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



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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:

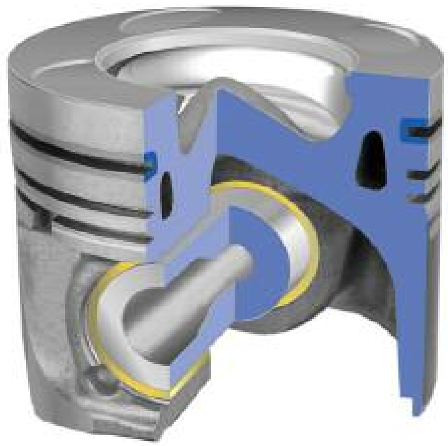
When making repairs which concern malfunctions of the crankcase ventilation system. Or, if any repairs are made to a turbocharger which has leaked oil into the engine, be sure to remove any residual oil in the intake air system.

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

Pistons, Crankshaft and Connecting Rods

One of the major differences between gasoline and diesel engines is in the pistons. The pistons on a diesel engine are subjected to very high pressures and therefore must be considerably stronger. On the diesel piston, a portion of the combustion chamber is in the crown.

Piston, diesel engine - typical



Piston - Diesel Engine

As can be seen from the above graphic, the diesel piston is more robust. The piston crown and skirt are noticeably thicker. As far as material is concerned, a stronger aluminum alloy is used. The area between the piston crown and the first ring land (fire land) is much larger than that used on a gasoline engine.

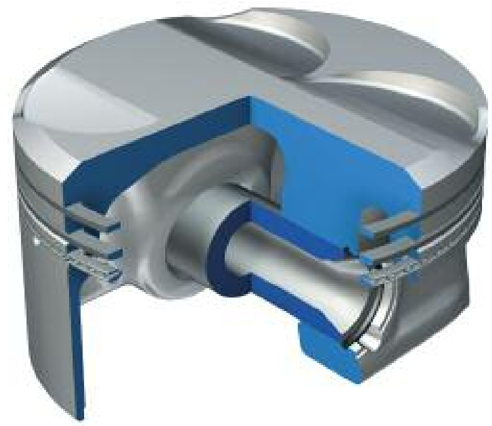
The piston crown itself is unique and features minimal valve reliefs and a large recess. This recess is used to accommodate the injector spray pattern and assist in mixture formation. The piston pin is also larger and features a bushing in the piston pin boss.

An oil cooling passage in the piston allows for a jet of pressurized oil to completely encompass the underside of the piston to keep it piston crown cool. The increases piston and ring life while helping to lower NO_X.

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.

Piston, gasoline engine - typical



Piston - Gasoline Engine

This gasoline piston above reflects the type used on a conventional gasoline engine. The piston skirt as compared to the diesel piston is quite thin. The design goals on a gasoline piston include making a strong but lightweight unit which is also "friction optimized".

The valve reliefs are more pronounced to accommodate additional valve lift. The piston pin is smaller and tapered to save weight without compromising strength.

In order to contain the additional forces generated in the diesel combustion cycle, the crankshaft is made from forged steel, cast iron crankshafts are not used. In some cases, the crankshaft journal diameters are slightly larger as well. This is dependent upon the engine version.

The connecting rods must also be stronger to accommodate the additional forces from the combustion process. To accomplish this, the rods made from forged steel and are significantly thicker in the beam area and have a larger piston pin.

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.

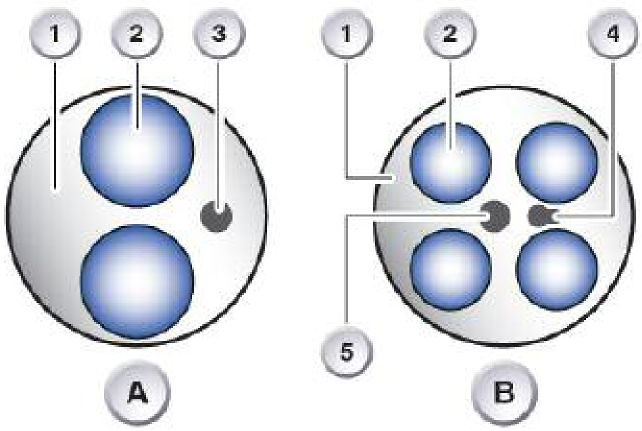
Future engine designs will use completely “lead-free” bearings.

Note: Crankshaft pictured above is not a US version, due to the location of the crankshaft speed sensor wheel.

Cylinder Head and Valvetrain

The cylinder head on a diesel engine differs in several ways as compared to a cylinder head on a gasoline engine. Obviously there are no accommodations for spark plugs, but rather glow plugs are centrally located in the combustion chamber.

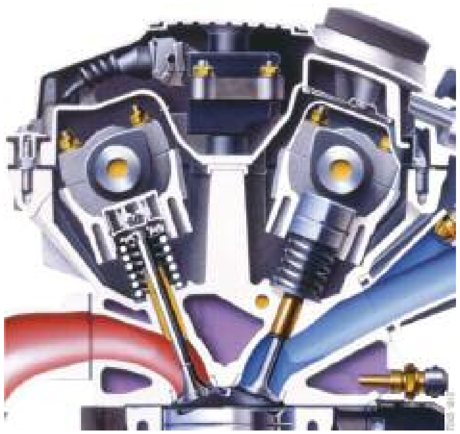
The fuel injector is also located centrally in the combustion chamber adjacent to the glow plug.



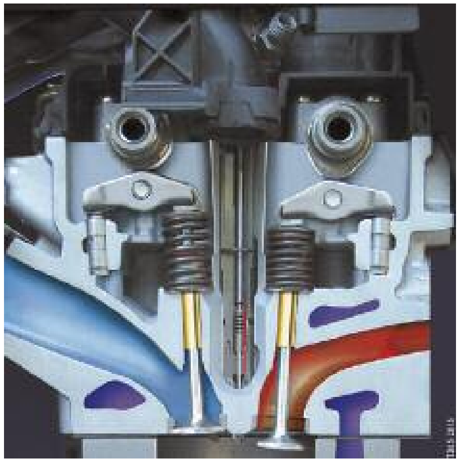
Index	Explanation
A	2-Valve arrangement (i.e. M21)
B	4-valve arrangement (i.e. M57)
1	Combustion chamber (surface/ceiling)
2	Valves
3	Injection port (swirl chamber/glow plug integrated)
4	Glow plug
5	Injector (direct injection)

The angle of the valves on a BMW diesel engine are also slightly different as compared to a gasoline engine. Gasoline engines depend upon the optimization of intake air flow to meet volumetric efficiency requirements. So, BMW gasoline engines depend upon the design of the intake and cylinder head to achieve these goals.

On the other hand, diesel engines are already efficient in this area due to the fact that the throttle is open most of the time. This reduces pumping losses and improves air flow with out the use of special designs. When comparing the cross-sectional views of the two cylinder heads below, notice the angle of the valves. The gasoline engines utilizes a more extreme angle between the intake and exhaust valves to improve flow and help form the shape of the combustion chamber. The diesel engine has a valve layout that is much less extreme and the combustion chamber is relatively non-existent.



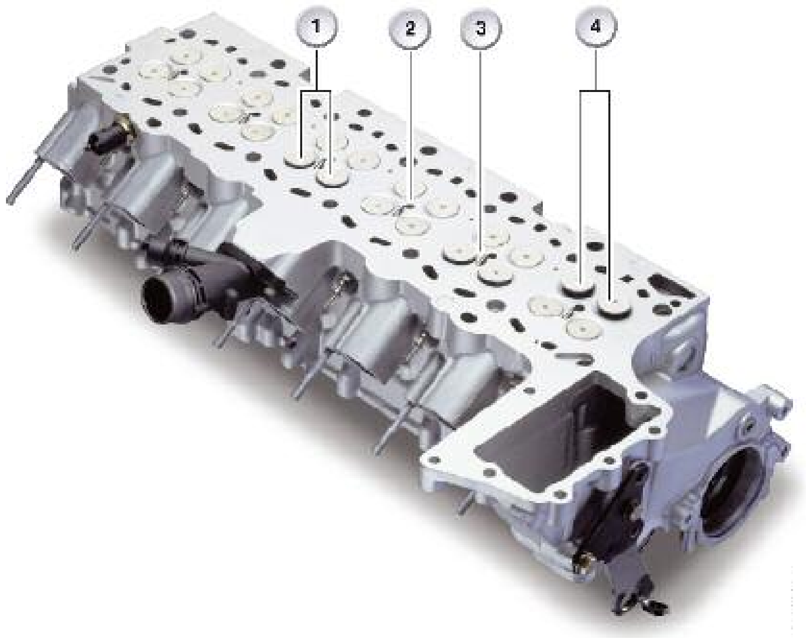
Cylinder head cross section
Gasoline Engine



Cylinder head cross section
Diesel Engine

It is also important to note that the intake and exhaust valves on gasoline engines are of different sizes, with the intake valves being larger than the exhaust valves.

The N54 engine, for example, has intake valves which are 31.5 mm and exhaust valves of 28 mm diameter. Some of the earlier diesel engines have had valves which are the same size. The M57TU1 TOP, which is not a US version engine, has a valve diameter of 25.9 mm for all valves, both intake and exhaust. However, the M57TU2 TOP (M57D30T2) uses only a slightly larger intake valve of 27.4 millimeters.



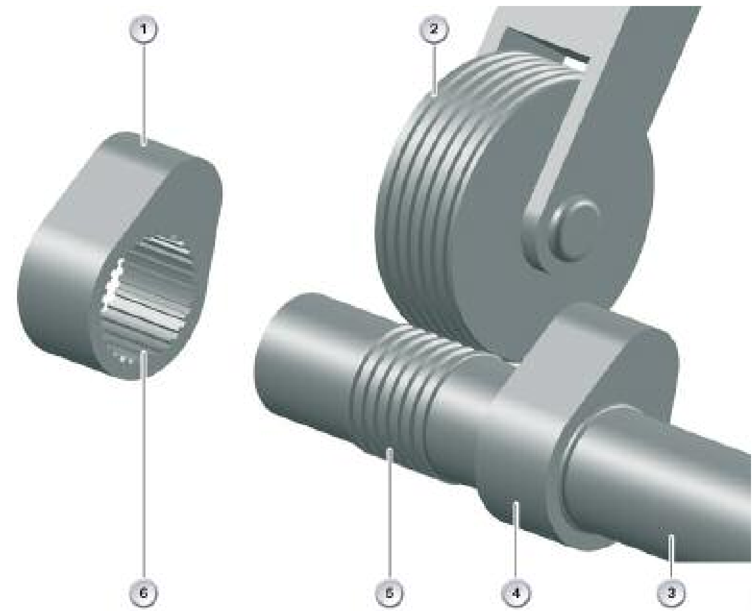
Index	Explanation
1	Intake valves (27.4 mm)
2	Injector (direct injection)
3	Glow plug
4	Exhaust valves (25.9 mm)

Camshafts

The camshafts on the M57 are a composite design for weight savings. This process is referred to as the “Presta” process which uses a steel tube for the camshaft. The tube is rolled to create a “knurled” area around it’s circumference.

The lobes have splines which interfere with the knurling on the camshaft tube. The lobes are pressed on and locked to the camshaft in the specified positions.

This process provides strength with a considerable reduction in weight.

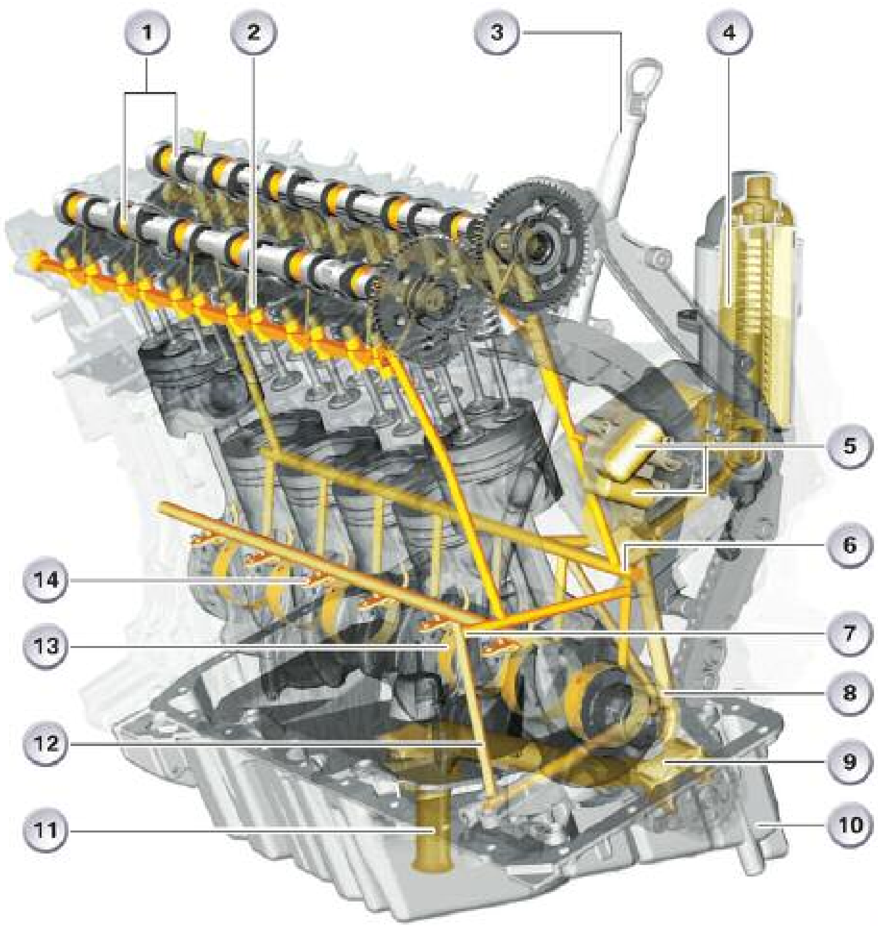


Index	Explanation
1	Camshaft lobe
2	Roller for Presta process
3	Camshaft (steel tube)
4	Camshaft lobe (locked on to steel tube)
5	“Knurling” on camshaft
6	Internal splines on camshaft lobe

Lubrication System

The oil circuit serves the purpose of supplying with oil all points in the engine requiring lubrication and cooling. As with all BMW engines, the diesel engine is equipped with a forced feed lubrication system. The oil drawn in by the oil pump from the oil pan via an intake pipe flows through the full-flow oil filter and then passes into the main oil gallery or channel which normally runs parallel to the crankshaft in the engine block.

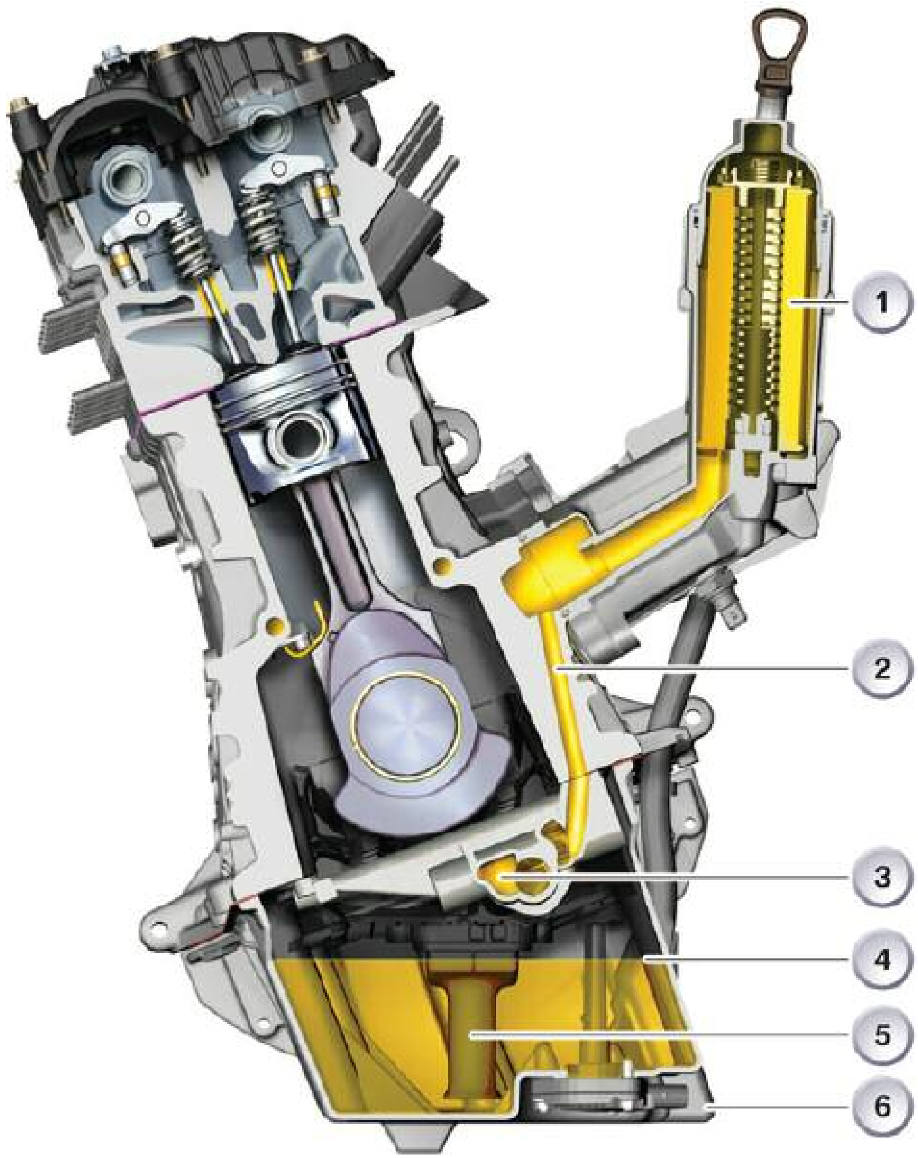
Branch galleries lead to the main bearings of the crankshaft. The crankshaft has corresponding holes to feed oil from the main bearings to the crankpins and connecting rod journals. Part of the oil is branched off from the main oil gallery and fed to the corresponding lubrication points in the cylinder head. The following system overview uses the M57 engine as an example to demonstrate the general layout of the oil circuit.



Index	Explanation
1	Camshaft bearing
2	HVA
3	Oil dipstick
4	Oil filter
5	Chain tensioner
6	Main oil gallery
7	Oil supply, exhaust turbocharger
8	Unfiltered oil gallery
9	Oil pump
10	Oil pan
11	Intake pipe with screen
12	Channel for oil spray nozzles
13	Crankshaft bearing
14	Oil spray nozzle

From Oil Pan to Oil Pump

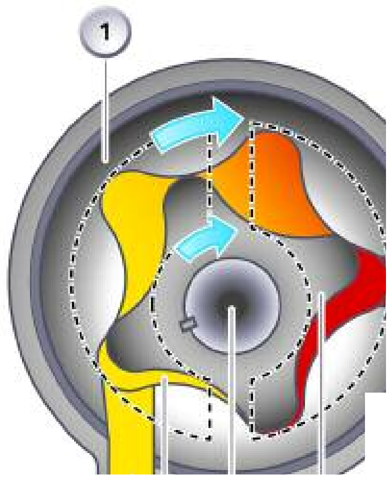
The oil pump (3) draws in oil from the oil pan (6) via the intake pipe with oil screen (5). The intake pipe is positioned such that the intake opening is above the oil level (4) under all operating conditions. An oil screen is integrated in the intake pipe in order to keep coarse dirt particles away from the oil pump.



Index	Explanation
1	Oil filter
2	Unfiltered oil gallery
3	Oil pump
4	Oil level
5	Intake pipe with oil screen
6	Oil pan

Oil Pump

Different types of oil pump are used on BMW engines. On the current diesel engines, a rotor type pump is used.



Index	Explanation
1	External gearwheel
2	Pressurized oil
3	Pressure chamber
4	Internal gearwheel
5	Driveshaft
6	Intake chamber
7	Oil intake

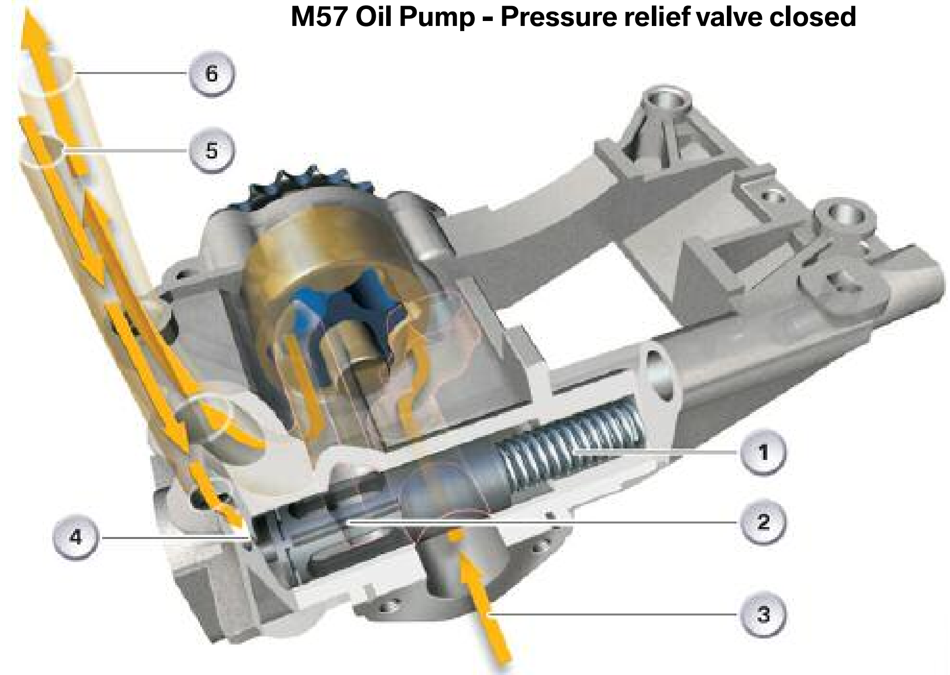
Functional Principle

The oil is drawn in by the rotor oil pump and delivered to the pressure side. The oil flows via the oil gallery (6) to the oil filter and then into the main oil gallery. The oil flows back into the oil pump housing via a filtered oil gallery (5) where it is used, for example, to supply the oil spray nozzles for piston cooling.

The control chamber of the pressure relief valve is connected to this filtered oil gallery (5) by means of a hole (4). Consequently, the system pressure in the oil circuit is also applied in the control chamber.

The control piston (2) which is actuated by compression spring (1) forms the limit on one side of the control chamber. The spring force of the compression spring (1) determines the opening pressure of the pressure relief valve.

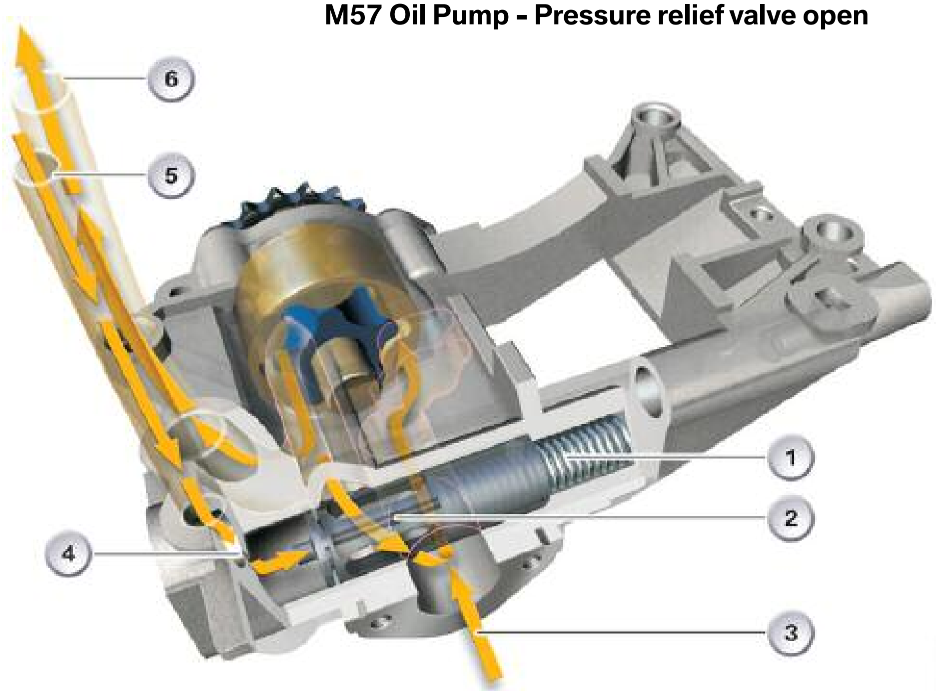
M57 Oil Pump - Pressure relief valve closed



Index	Explanation
1	Compression spring
2	Control piston
3	Oil intake
4	Hole
5	Filtered oil gallery
6	Oil gallery to oil filter

The control piston (2) is moved against the spring force when the system pressure in the oil circuit, i.e. also in the control chamber, increases. The special shape of the control piston (2) opens up a connection from the pressure side of the rotor oil pump to the intake.

M57 Oil Pump - Pressure relief valve open



Index	Explanation
1	Compression spring
2	Control piston
3	Oil intake
4	Hole
5	Filtered oil gallery
6	Oil gallery to oil filter

The oil circuit is short-circuited. Determined by the pressure conditions, a certain quantity of oil consequently flows off from the pressure side into the intake. The greater the control piston (2) is opened, the greater the amount of oil that flows off so that the system pressure drops.

Since the control piston (2) is opened by the system pressure, equilibrium is established. In this way, a required maximum pressure in the system is now exceeded as it is determined by the force of the compression spring (1).

There are two reasons for applying oil pressure to the pressure relief valve downstream of the oil filter:

- The oil pressure actually in the system is applied and not the pressure between the oil pump and oil filter. If the oil filter were soiled, this pressure would be higher and the pressure relief valve would open before the maximum pressure were reached in the system.
- The oil is calmed in the oil filter. Consequently, the pressure relief valve is not subjected to pressure peaks thus enabling more exact valve operation.

Pressure Relief Valve

The pressure relief valve protects against excessively high oil pressure, e.g. when starting the engine with the oil cold. In turn this function protects the oil pump, oil pump drive, oil filter and oil cooler.

The pressure relief valve is installed on the delivery side between the oil pump and oil filter. The pressure relief valve is arranged as close as possible downstream of the oil pump, often directly in the oil pump housing.

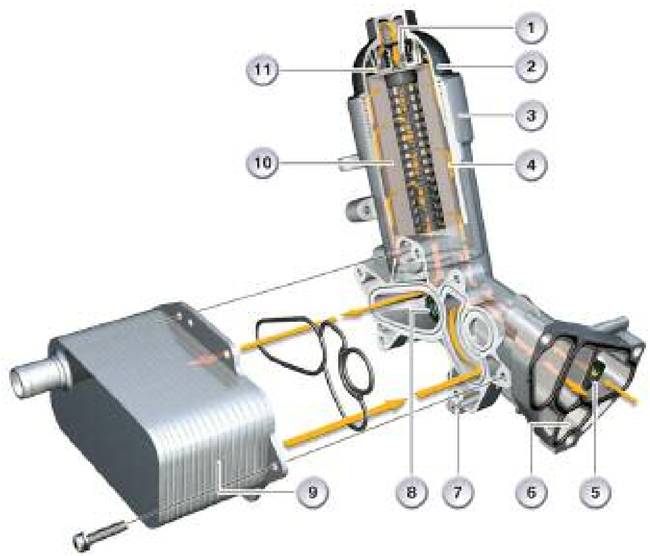
The opening and control pressure depends on the respective type of engine and is between 3 bar and 5. Specifically, the control pressure on the M57TU2 is 4.0 bar.

Oil Filtering

The purpose of the oil filter is to clean the oil and to prevent dirt particles from entering the oil circuit. BMW diesel engines use the full-flow oil filter which allows the entire volume of oil conveyed by the oil pump to pass through the filter before it is fed to the lubrication points.

From the oil pump, the oil is fed into the oil filter module and then to the cooling system corresponding to requirement and version.

The oil filter module contains valves that fulfill various tasks, which include draining facility for filter change, filter bypass in the case of clogging and preventing the oil galleries running empty.



Index	Explanation	Index	Explanation
1	Filter bypass valve	7	Oil pressure switch
2	Oil filter cover	8	Heat exchanger bypass valve
3	Oil filter housing	9	Oil-to-coolant heat exchanger
4	Oil flow	10	Oil filter
5	Non-return valve	11	Oil flow via filter bypass valve
6	Oil drain opening		

The oil filter cover (2) is connected to the oil filter housing (3) by means of a long threaded stud. When the oil filter cover (2) is removed, the threaded stud releases an oil drain opening (6), via which the oil filter housing (3) can be emptied.

Note: The seals for the threaded connection of the oil filter cover must always be replaced as part of the oil service procedure. The seals are supplied together with the genuine oil filter. The screw connection for the oil filter cover must be tightened to a specified torque, which is defined in TIS.

Non-return Valve

The oil pump pumps the oil into the oil filter (10). A non-return valve (5) prevents the oil filter (10) draining empty when the engine is not running. This function ensures the lubrication points are supplied with oil for engine start. The oil must overcome an opening pressure in the non-return valve (5) of 0.2 bar. Drained oil galleries can cause noise or even poor engine performance shortly after starting an engine that has been stationary for a longer period of time.

Filter Bypass Valve

The system features a filter bypass valve (11) for the purpose of maintaining the oil supply to the lubrication points even when the oil filter (10) is soiled. If the oil pressure increases because the oil filter (10) is clogged, the filter bypass valve (11) will open at an overpressure of 2.5 bar and the oil will flow (unfiltered) to the lubrication points.

Heat Exchanger Bypass Valve

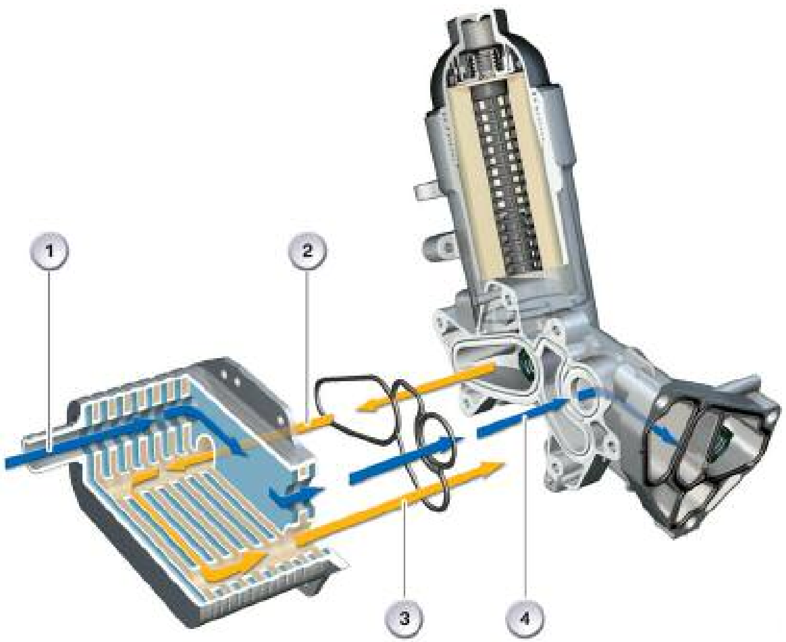
The heat exchanger bypass valve (8) has the same function as the filter bypass valve (1). If the oil pressure increases because the oil-to-coolant heat exchanger (9) is clogged, the heat exchanger bypass valve (8) will open at a pressure of 2.3 bar, allowing the lubricating oil (not cooled) to flow to the lubrication points.

Engine Oil Cooling

There is a risk on high-performance engines and engines subject to high thermal loads that the lubricating oil becomes too hot during vehicle operation. In this case, the viscosity decreases - the oil looses its lubricity and oil consumption increases.

This results in deposits in the combustion chamber. The oil film can break down causing bearing and piston damage. These problems can be avoided by the use of an engine oil cooler.

These additional coolers are used if the thermal losses can no longer be dissipated over the surface of the oil pan or housing so that the permitted oil temperatures would be exceeded. Oil-to-air or oil-to-coolant heat exchangers are used for the purpose of cooling the oil.



Index	Explanation	Index	Explanation
1	“Cooled” coolant	3	“Cooled” engine oil
2	“Hot” engine oil	4	Heated coolant

Oil-to-air Heat Exchanger

A conventional engine oil cooler is designed as an oil-to-air heat exchanger. This means the heat is given off from the oil to the ambient air with no further medium involved. The design of such an engine oil cooler is comparable to that of a coolant radiator.

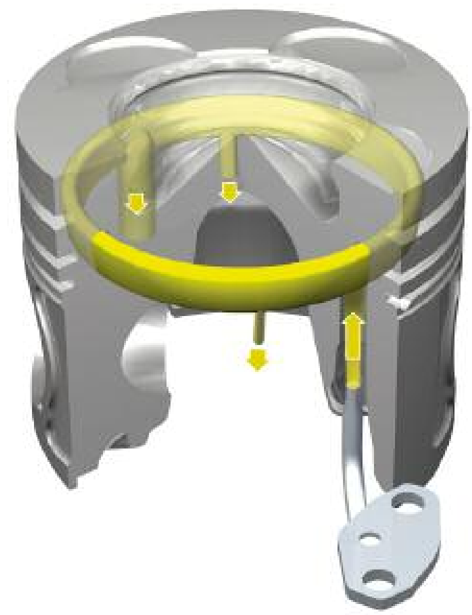
The oil flows through the engine oil cooler with its large surface area facilitating effective heat dissipation.

Oil-to-coolant Heat Exchanger

Oil-to-coolant heat exchangers are used in the engine oil and transmission fluid heat management system. They ensure the oil heats up rapidly while sufficiently cooling the oil. Engine oil and coolant counterflows through the oil-to-coolant heat exchanger on several planes, thus transferring heat from one fluid to the other.

Oil Spray Nozzles

Oil spray nozzles are used to feed oil for lubrication or cooling purposes to defined positions of moving parts that cannot be reached via oil galleries.



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.

Diesel Engine Management

In comparison to the first BMW diesel engine, the M21D24, modern diesel technology has evolved considerably throughout the past 20 years. The early engines were not "managed", that is to say that there were only minimal electronic systems involved. The injectors were mechanical and there were no feedback systems in place such as O_2 sensors etc.

Modern diesel engines have benefitted from the advances in current gasoline engine management technology. The Digital Motor Electronics (DME) systems have been adapted to the needs of the diesel engine in the form of Digital Diesel Electronics (DDE).

DDE systems constitute many of the same components and systems as their gasoline powered "cousins". Some of the familiar items include electronically controlled injectors, O_2 sensors as well as other common sensors including crankshaft and camshaft sensors.

The main goals of DDE include the reduction of emissions and maximization of engine efficiency and fuel economy. Also, the ability to have more precise control of the injection process allows modern diesel engines to have reduced noise emissions. Engine noise has long been a negative aspect of diesel engines.

The Digital Diesel Electronics (DDE) systems have gone through a progression of enhancement and improvements since the first DDE system was introduced on the M21 engine.

The early development of DDE systems began with the M21D24 engine in 1987. The first generation of diesel engine management was referred to as DDE 1. Over the past 20 years of development, the DDE has seen numerous improvements in processing speed and computing power.

These advancements have allowed for more precise control over the fuel injection system. This precise control has allowed for a significant reduction in emissions and a considerable improvement in fuel economy. Soot, smoke, NOx have all been reduced by optimizing the injection strategy.

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 (DDE 7.3)

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.

The ECM is the computational and switching center for the DDE system. Sensors installed on the engine and in the vehicle provide the input signals for the DDE.

Actuators execute the commands of the DDE. The DDE calculates the necessary control signals for the actuators from the input signals together with the computational models and characteristic maps stored in the DDE.

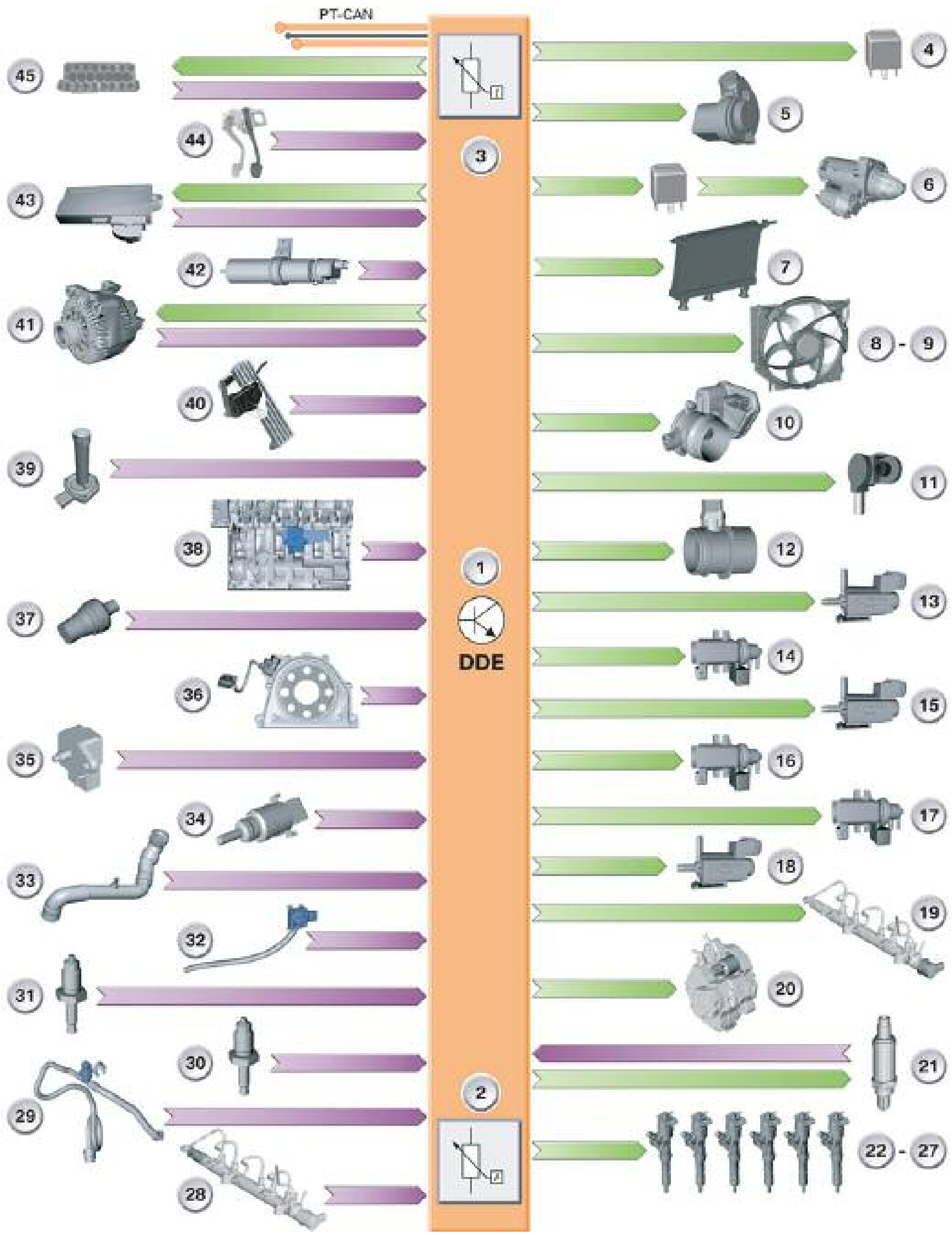
DDE operation is guaranteed with a system voltage of between 6 V and 16 V. An ambient pressure sensor and a temperature sensor are integrated in the DDE.

The ambient pressure sensor makes it possible for the density of the ambient air to be precisely determined - a variable that is used in numerous diagnostic functions. Furthermore, it is needed if the cylinder charge is being calculated from the substitute variables in the event of a hot-film air mass meter fault, for example.

The temperature sensor measures the temperature inside the control unit. If the temperature there increases to excessively high levels, the multiple injection, for example, is reduced in order to cool down the output stages a little and to maintain the temperature inside the control unit within a non-critical range.

Typical DDE System

DDE 606
M57TU1TOP
(Not for US Market)



Index	Explanation	Index	Explanation
1	Digital Diesel Electronics (DDE)	22-27	Fuel injectors
2	Ambient pressure sensor in control unit	28	Rail pressure sensor
3	Temperature sensor in control unit	29	Fuel temperature sensor
4	DDE Main relay	30	Exhaust gas temperature sensor 1
5	E-box fan	31	Exhaust gas temperature sensor 2
6	Starting relay with starter	32	Exhaust pressure sensor
7	Auxiliary heater	33	Intake air pressure sensor
8-9	Electric fan with fan control	34	Coolant temperature sensor
10	Throttle valve actuator	35	Boost pressure sensor
11	Camshaft position sensor	36	Crankshaft position sensor (KWG)
12	Hot-film Air Mass Meter	37	Oil pressure switch
13	Electric changeover valve (EUV) for engine mount control	38	Preheating control unit
14	Electro-pneumatic pressure converter (EPDW) for low pressure exhaust gas recirculation (EGR) E70 only	39	Oil level sensor (Töns or QLT)
15	Electro-pneumatic pressure converter (EPDW) for turbine control valve	40	Accelerator pedal module
16	Electro-pneumatic pressure converter (EPDW) for wastegate	41	Alternator
17	Electric changeover valve (EUV) for compressor bypass valve	42	Diagnosis line for fuel filter heating
18	Electric changeover valve (EUV) for swirl flaps (not US)	43	Car Access System
19	Rail pressure control valve	44	Brake light switch
20	Volume control valve	45	On-board diagnostics socket
21	Broadband oxygen sensor (LSU 4.9)	46	Ground connection

Sensors and Actuators

Sensors

- Accelerator pedal module
- Hot-film air mass meter (HFM)
- Boost pressure sensor
- Coolant temperature sensor
- Fuel temperature sensor
- Rail pressure sensor
- Charge air temperature sensor
- Camshaft position sensor (NWG)
- Thermal oil level sensor (TÖNS)
- Crankshaft position sensor (KWG)
- Exhaust pressure sensor
- Exhaust gas temperature sensor upstream of DOC
- Exhaust gas temperature sensor upstream DPF
- Oxygen sensor Bosch LSU 4.9 with constant characteristic

Actuators

- Fuel injectors 1-6
- Volume control valve
- Pressure control valve
- Electric changeover valve (EPDW) for low pressure exhaust gas recirculation E70 only
- Electric valve (EL) for swirl flaps
- Electric changeover valve (EUV) for engine mounts
- E-box fan
- Electric motor throttle valve actuator
- Electro-pneumatic pressure converter (EPDW) for turbine control valve
- Electro-pneumatic pressure converter (EPDW) for wastegate
- Electric changeover valve (EUV) for compressor bypass valve

Switches

- Brake light switch/brake light test switch
- Oil pressure switch
- Clutch switch

Relays

- DDE main relay
- Starter relay

Interfaces

- Bit-serial data interface BSD (alternator, preheating control unit)
- PT-CAN

Electro-pneumatic Pressure Converter (EPDW)

(EPDW) apply vacuum to the diaphragm units of the turbine control valve and wastegate. The DDE uses a PWM signal (300 Hz) to actuate the EPDW. The nominal voltage is 12 V.

Electric Changeover Valve (EUV)

An electric changeover valve (EUV) applies vacuum to the diaphragm unit of the compressor bypass valve. The DDE controls the EUV. The nominal voltage is 12 V.

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

Sensors	EURO 4	E70 US	E90 US
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

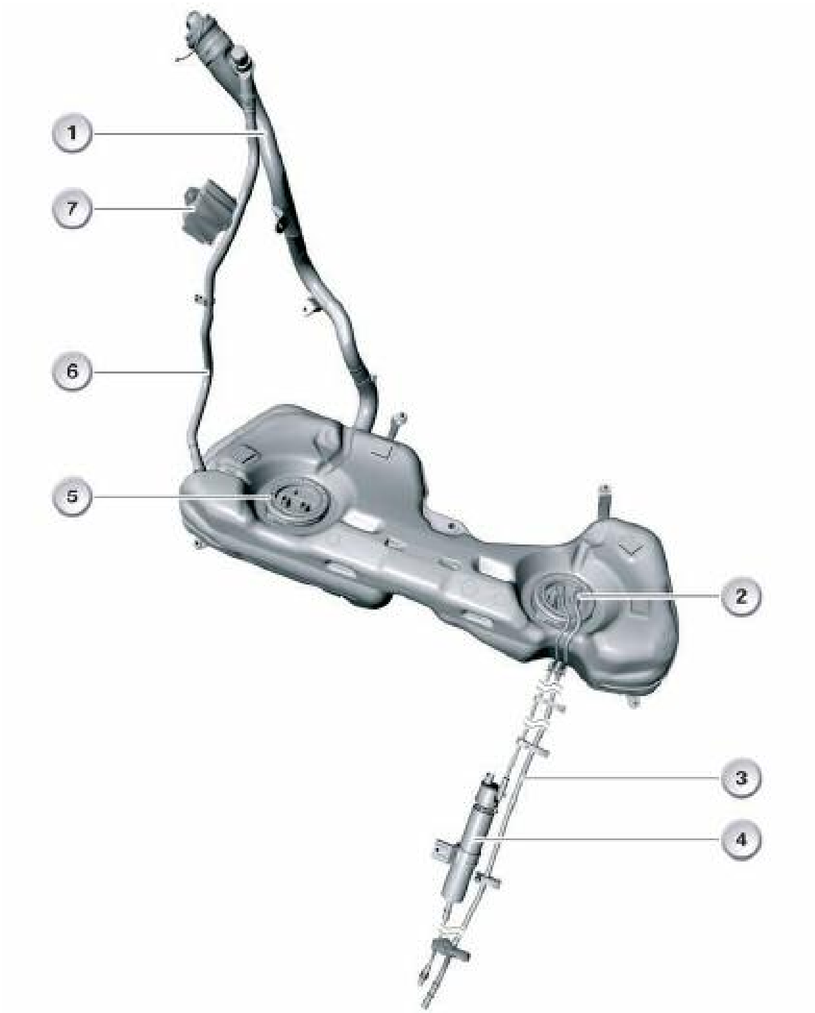
EL
Electrically actuated

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

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

Low Pressure 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.

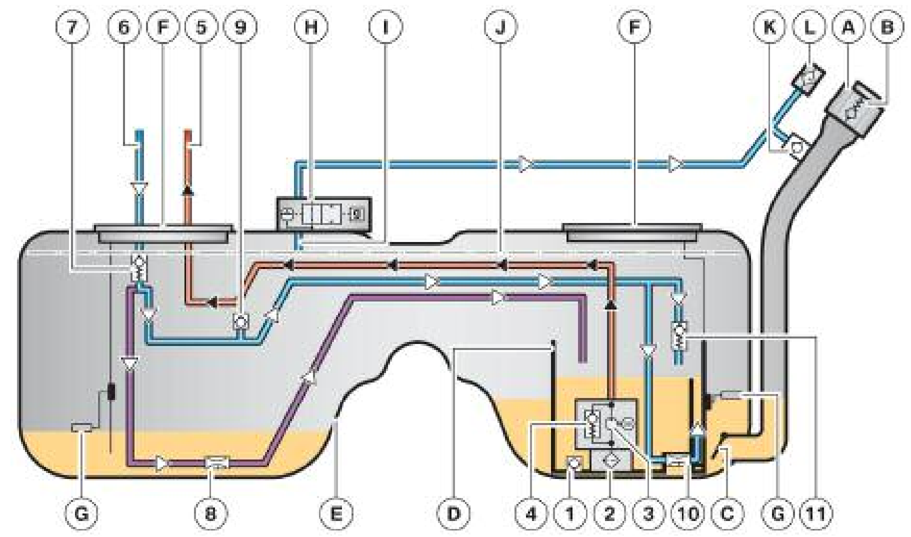
So, the fuel tanks in the diesel vehicles feature the familiar “double-chamber” configuration. This design feature accommodates two delivery units which are located in the right and left fuel tank halves.

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.

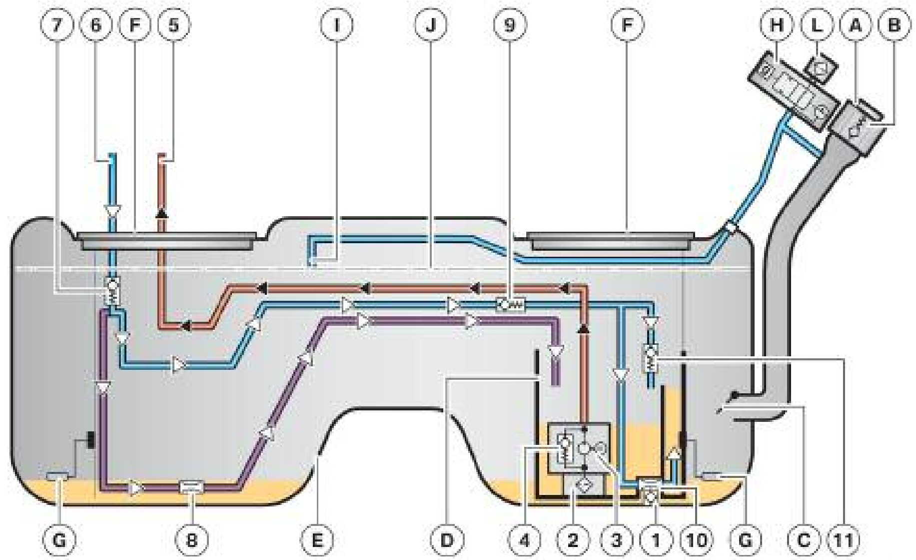
A line leads from the filler vent valve (H) to the filter (L). The fuel filler pipe is connected to this line via the non-return valve (K).

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

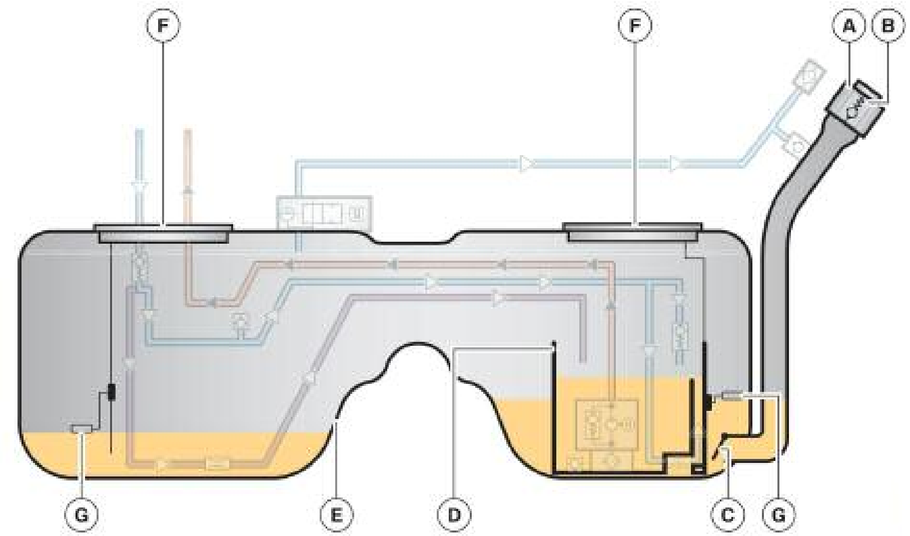


Index	Explanation	Index	Explanation
A	Fuel filler cap	1	Initial fill valve
B	Pressure relief valve	2	Intake mesh filter
C	Non-return valve	3	Fuel pump
D	Surge chamber	4	Pressure relief valve
E	Fuel tank	5	Feed line
F	Service cap	6	Return line
G	Lever-type sensor	7	Leak prevention valve
H	Filler vent 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.

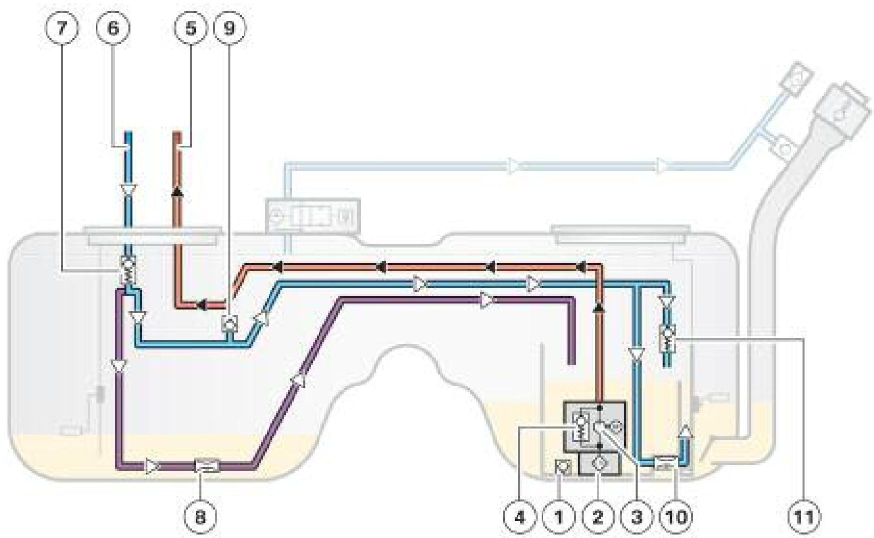


Index	Explanation	Index	Explanation
A	Fuel filler cap	E	Fuel tank
B	Pressure relief valve	F	Service cap
C	Non-return valve	G	Lever-type sensors
D	Surge chamber		

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.

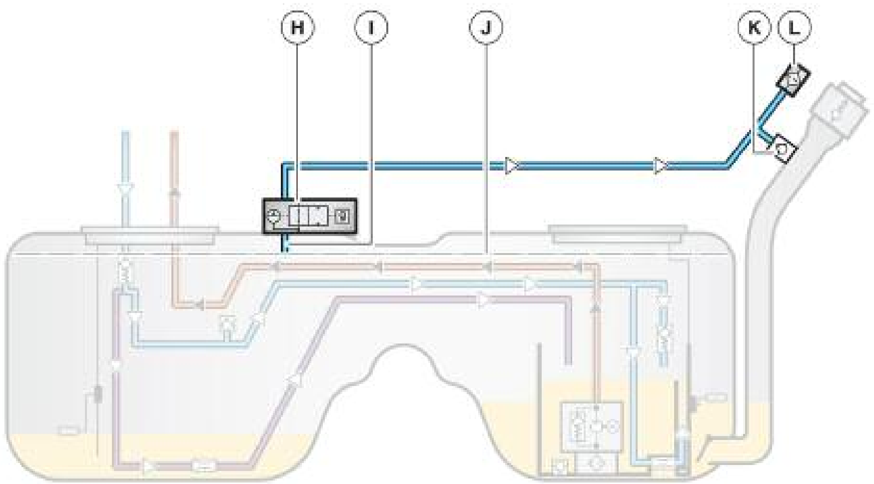
Instead of the air inlet valve (9) a non-return valve is used on the E90. The non-return valve ensures that, while the engine is off, fuel from the right-hand half of the fuel tank cannot flow back into the left-hand half. The return system remains completely filled with fuel.

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		

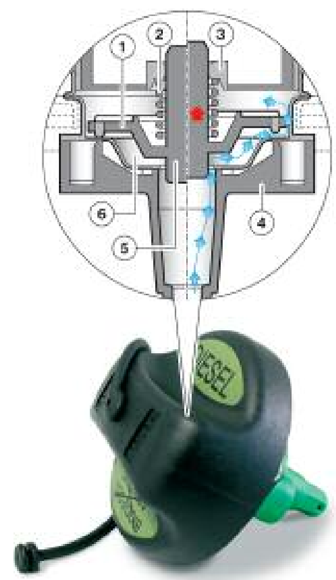
The filter (L) prevents dirt or insects from entering the ventilation and blocking the line.

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.

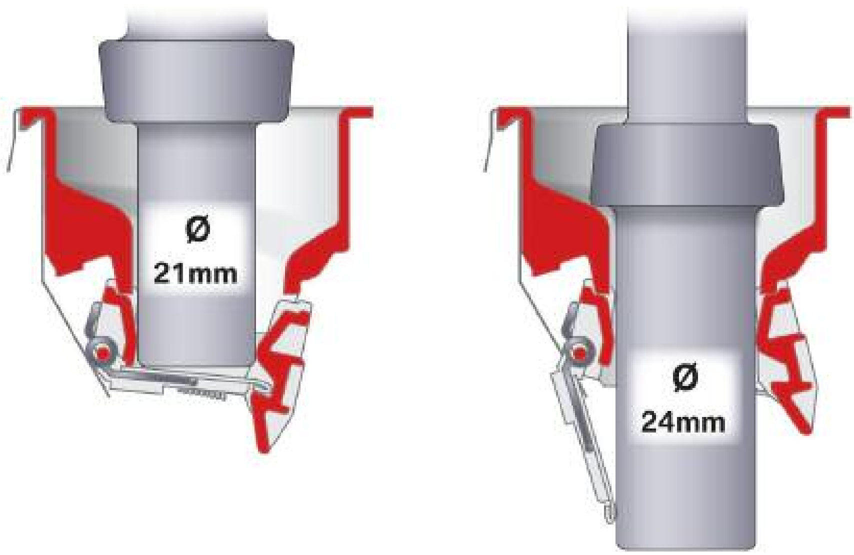
The excess pressure spring uses a defined pressure to push the pressure relief valve onto the sealed housing and is supported by the brace (3).

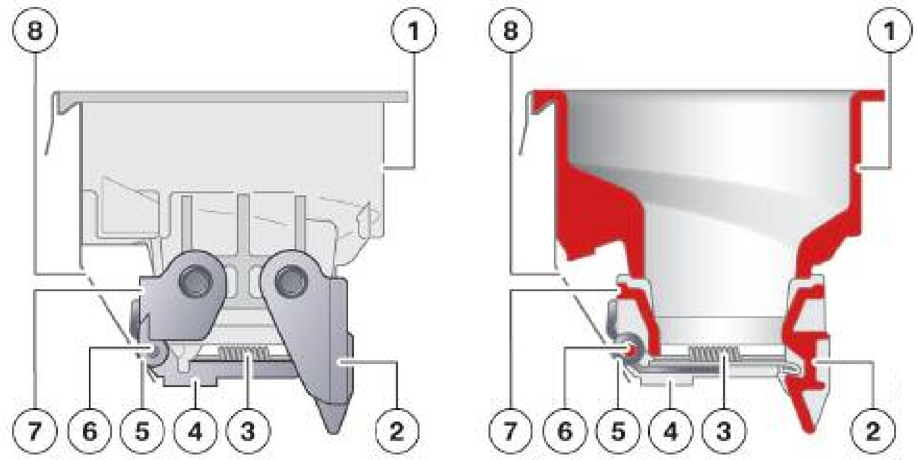


Index	Explanation
1	Valve head
2	Excess spring pressure
3	Brace
4	Bottom section of housing
5	Pressure relief valve
6	Sealed housing

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.

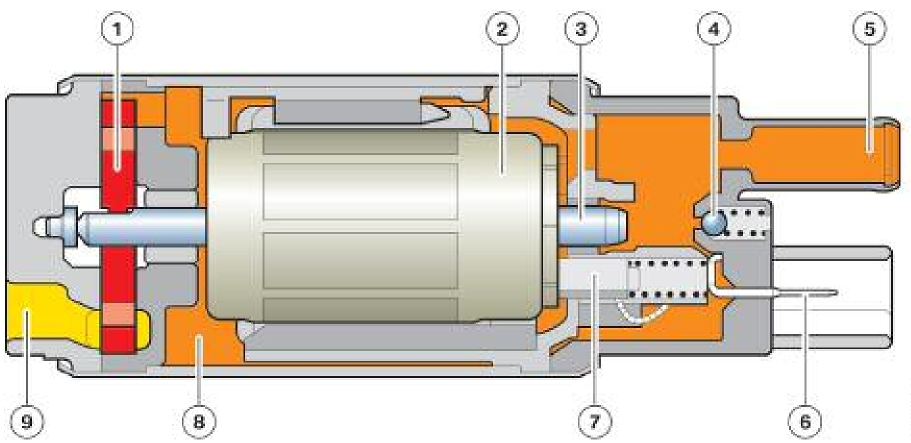
If a diesel fuel nozzle is inserted, this pushes the locking lever (2) and the hinged lever (7) at the same time. The hinged lever is pushed outwards against the tension spring (3) and releases the flap (4). This is only possible, however, if the hinged lever cannot move freely and is also locked in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

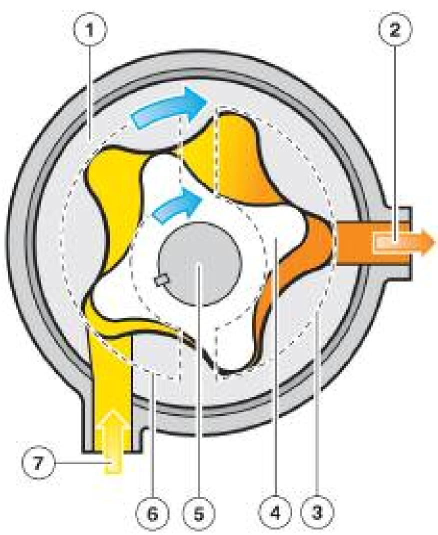
If the fuel delivery pressure increases to an impermissible value, the pressure relief valve (4) opens and allows the fuel to flow into the surge chamber.

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).

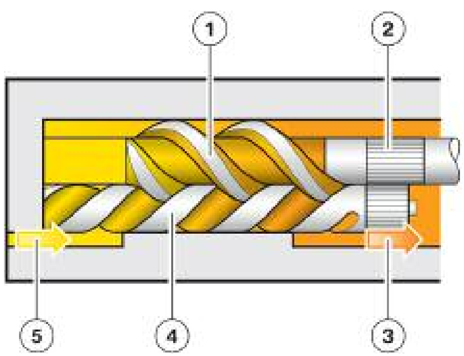


Index	Explanation
1	Outer rotor
2	Fuel delivery to engine
3	Pressure section
4	Inner rotor
5	Driveshaft
6	Intake section
7	Fuel from tank

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:

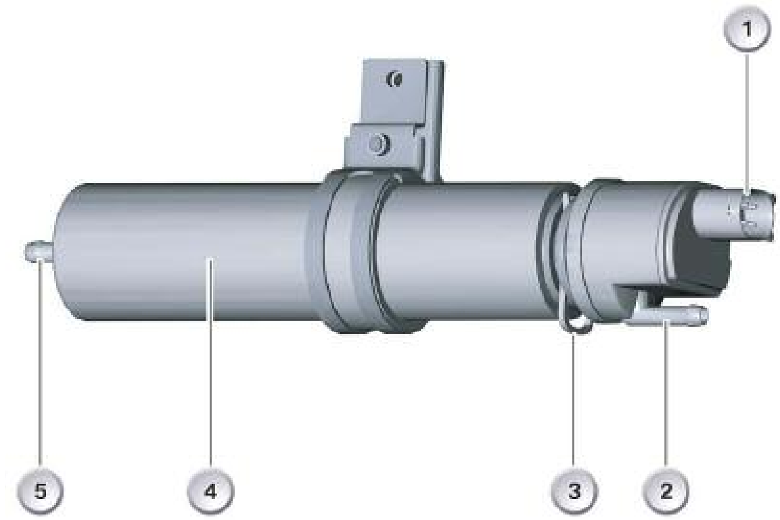
- Temperature drops below a defined value
- A defined fuel delivery pressure is exceeded due to cold, viscous fuel.

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 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.



Index	Explanation
1	Electrical connection
2	Low pressure fuel inlet
3	Retaining clip
4	Fuel filter housing
5	Fuel outlet

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:

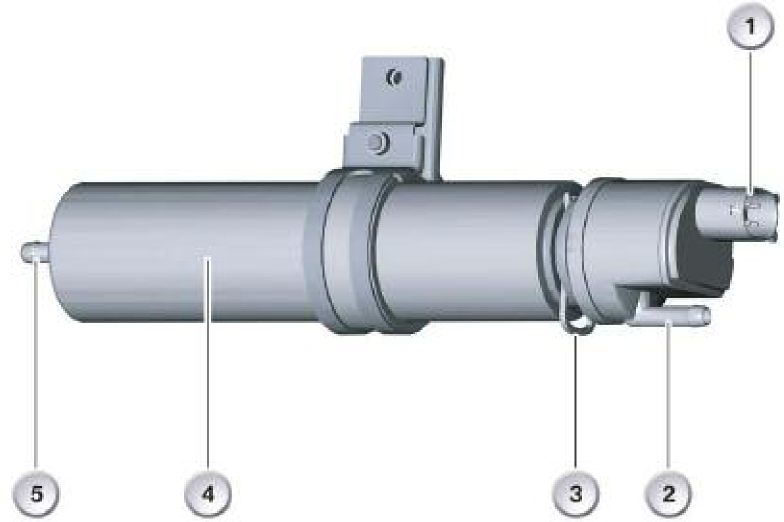
- Temperature drops below a defined value
- The required fuel pressure is not reached despite increased power intake of the electric fuel pump.

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:

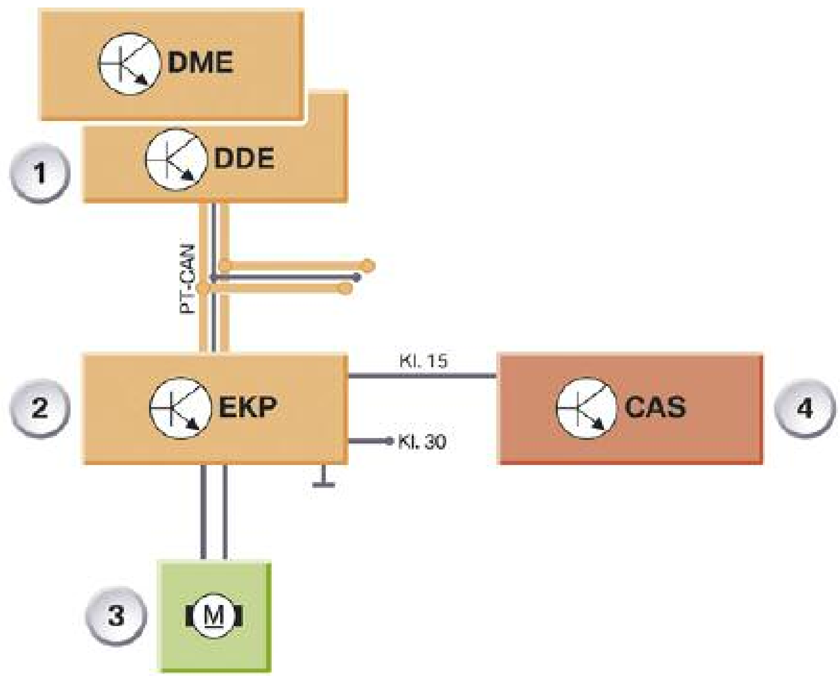
- Activation time > 5 min or
- Fuel temperature > 8°C or
- Battery voltage is less than 9 volts for more than 30 seconds



Index	Explanation
1	Electrical connection
2	Low pressure fuel inlet
3	Retaining clip
4	Fuel filter housing
5	Fuel outlet

EKP Control Module

The fuel pump is controlled by the DDE via the EKP module. The EKP module operates in much the same way as the gasoline version does. As in the past, the EKP module stores the fuel mapping requirements through vehicle specific encoding.



Index	Explanation
1	DDE Control Module
2	EKP Module
3	Fuel Pump
4	Car Access System

The EKP control module uses the mappings as the basis on which to calculate the total amount of fuel to be delivered from the following reference variables:

- Amount of fuel required by the engine (as a request from the DDE control unit)
- Amount of fuel needed to lubricate the high-pressure pump in the diesel fuel system (mapping in the EKP control unit).

This results in a pulse-width modulated output voltage from the EKP control module. The output voltage of the EKP control module is the supply voltage for the electric fuel pump. The EKP control module controls the speed of the electric fuel pump via the supply voltage. The speed of the fuel pump is compared to the actual specification stored in the EKP control module controls the speed by comparing the actual speed with the specification.

The current speed of the electric fuel pump is calculated as follows:

The EKP control unit sends the current supply to the fuel pump (pulse-width modulated). This voltage is absorbed as a specific ripple due to the individual armature windings of the rotating electric motor. The ripple corresponds with the number of segments in the commutator (= corresponds with the number of armature windings in the electric motor).

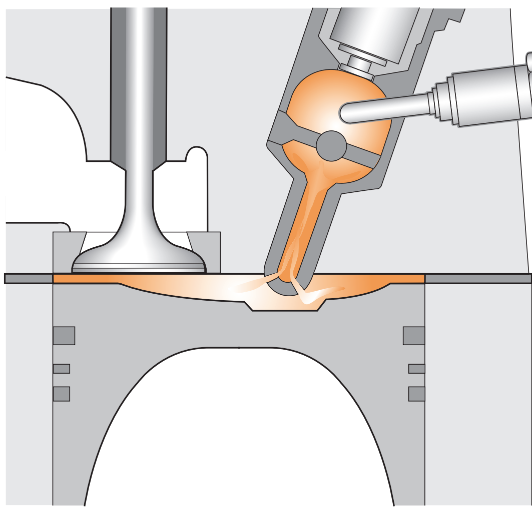
The number of waves produced per revolution is equal to the number of existing commutator segments.

This means that the EKP control unit can employ a patented procedure (= "Ripple Counter") as the basis for calculating the actual speed of the fuel pump using power consumption ripple.

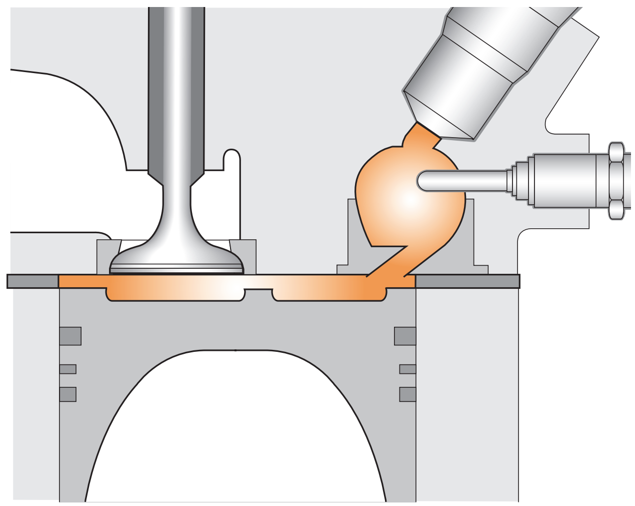
High Pressure Fuel Systems

There are two basic types of diesel injection methods used on BMW diesel engines. The early designs such as the M21 utilized the indirect injection (IDI) method (swirl chamber) which injects fuel into a pre-chamber rather than directly into the combustion chamber. Modern designs take advantage of direct injection (DI) which, as the name suggests, injects fuel directly into the combustion chamber.

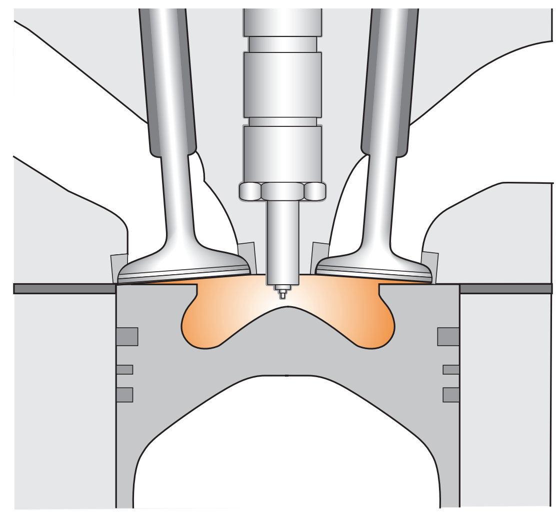
Indirect injection (IDI) can be broken down further into two groups. The “pre-chamber” design and the “swirl” (or turbulence) chamber design. As far as BMW current BMW diesel vehicles are concerned, the direct injection arrangement on the diesel is only used with common rail injection systems. Common rail was first introduced into BMW production diesels on the M57 family engines for the 1999 model year.



“Pre-chamber” design (IDI)



“Swirl-chamber” design (IDI)



“Direct Injection” design (DI)

The indirect method of injection was very popular on early engine designs such as the M21. The IDI systems offered advantages in emissions and engine noise reduction. Today, direct injection designs have replaced the IDI systems. This is due to the advanced high pressure common rail systems currently available. With electronic controls and high pressure injection, the new common rail systems have paved the way for direct injection to offer up to 20% fuel savings over the earlier designs.

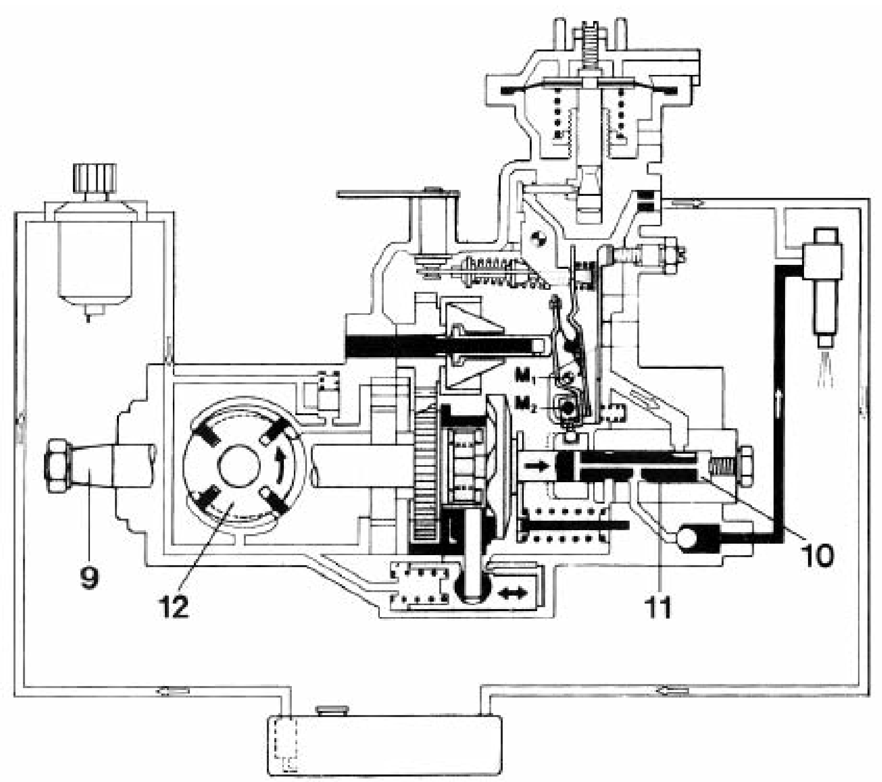
Now, with Digital Diesel Electronics (DDE) from BMW, the latest common rail systems are capable of providing multiple injection events. There is now the possibility of “pre” and “post” injection events. The pre-injection phase allows for a significant reduction in engine noise as compared to the earlier IDI systems.

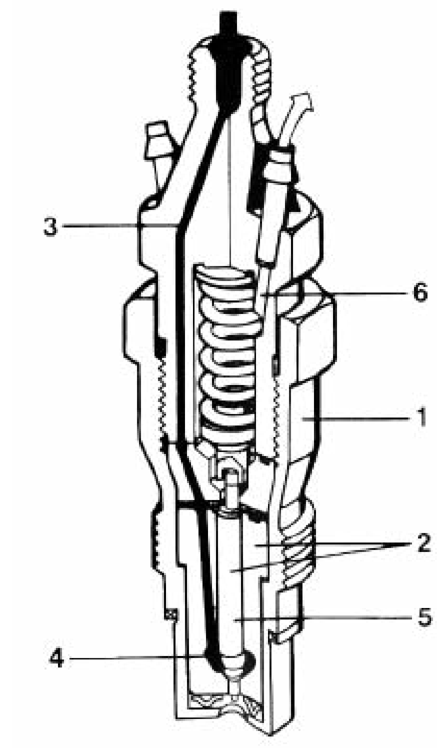
Distributor Type Diesel Injection

In order to understand how far diesel fuel injection technology has come, it is important to understand the fuel system which was used in the "early days" of BMW diesel development. The M21 engine used a mechanical injection system which had only minimal electronic intervention. The main method of engine control was the fuel pump which was a "distributor type". This meant that the fuel pump was responsible for creating the high pressure needed as well as the injection timing and distribution of the pressurized fuel to each cylinder.

Each of the fuel injectors on this system was mechanical, which means that the opening of the injector was pressure dependent. These injectors would open at a pressure of about 150 bar (2175 psi). This pressure was provided by the distributor injection pump at a specific time, this timing was crucial to engine operation. Much like the ignition timing on a "spark-ignition" engine, the timing of these events was vital to proper engine operation.

On the M21, the distributor type pump was mechanically driven by the engine, via the timing belt. This pump needed to be adjusted mechanically to ensure proper timing of the fuel injection events. This engine was quite efficient for it's time, however ever increasing emission legislation and fuel economy concerns drove the development of the future common rail injection systems.





Common Rail Fuel Injection

The common rail fuel system is divided into two parts - the low pressure system and the high pressure system. The low pressure system is responsible for supplying the high pressure mechanical fuel pump. The low pressure portion of the fuel system will be discussed in the subsequent pages.

The high pressure system is responsible for the fuel pressure generation required to supply the fuel injectors via the common rail.

The latest common rail technology is capable of generating injection pressures of more than 1600 bar (23,200 psi) and in some new systems up to 1800 bar (26,100 psi). The system is also capable of varying pressure as needed independently of injection timing and injection quantity.

The use of electronically controlled fuel injectors allows for more precise control over exhaust emissions and noise characteristics. The engine noise or “clatter” which is usually associated with diesel engines is greatly reduced by the modern common rail injection system.

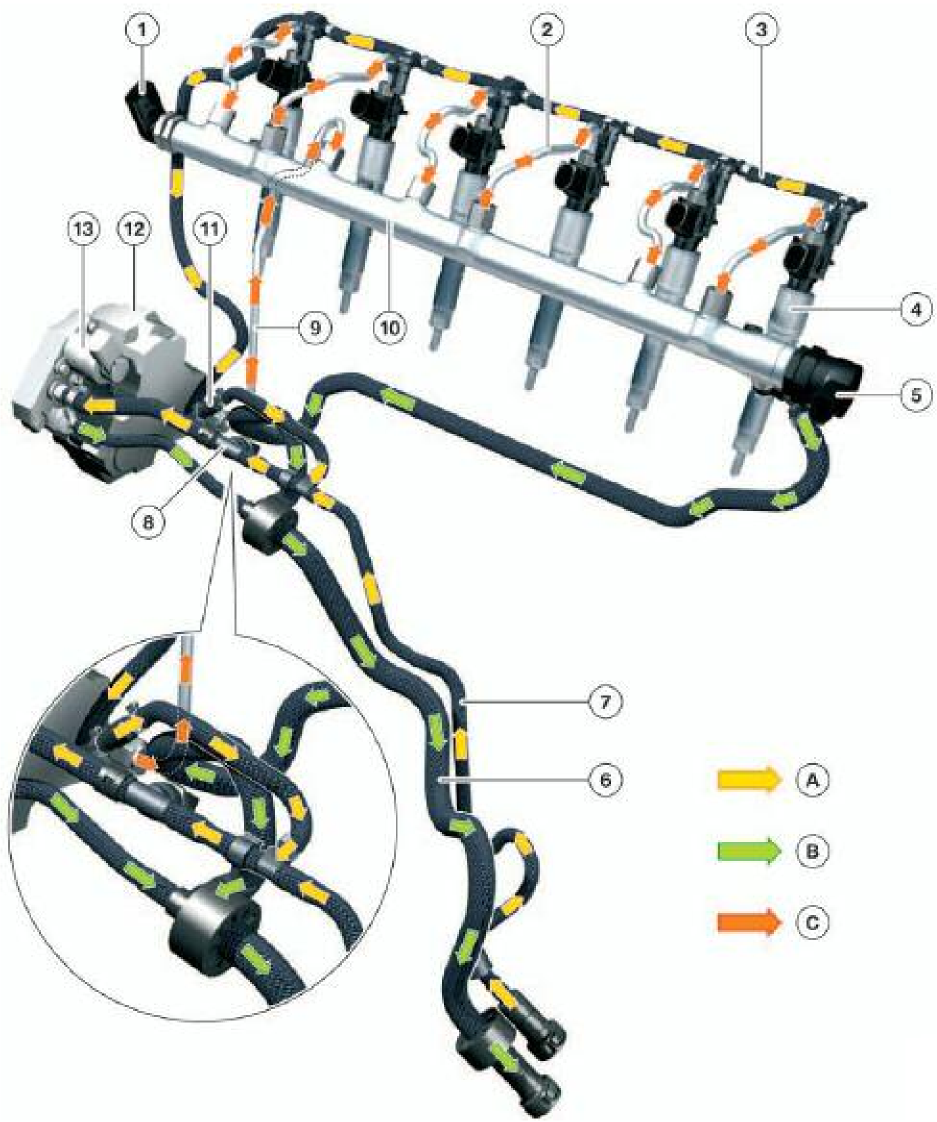
Common rail systems are referred to as “accumulator” systems due to the use of a fuel rail. The fuel rail stores pressurized fuel for use by the injectors. This type of system resembles a modern gasoline (direct) fuel injection system, but operates at considerably higher rail pressures.

From the inception of common rail systems, enhancements have been made to improve performance and emission levels. Current BMW vehicles are using the “3rd Generation” of common rail systems. These systems include such innovations as piezo-electric injectors, multiple injection phases and high-pressure CP3 (plus) pump.

NOTES PAGE

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.

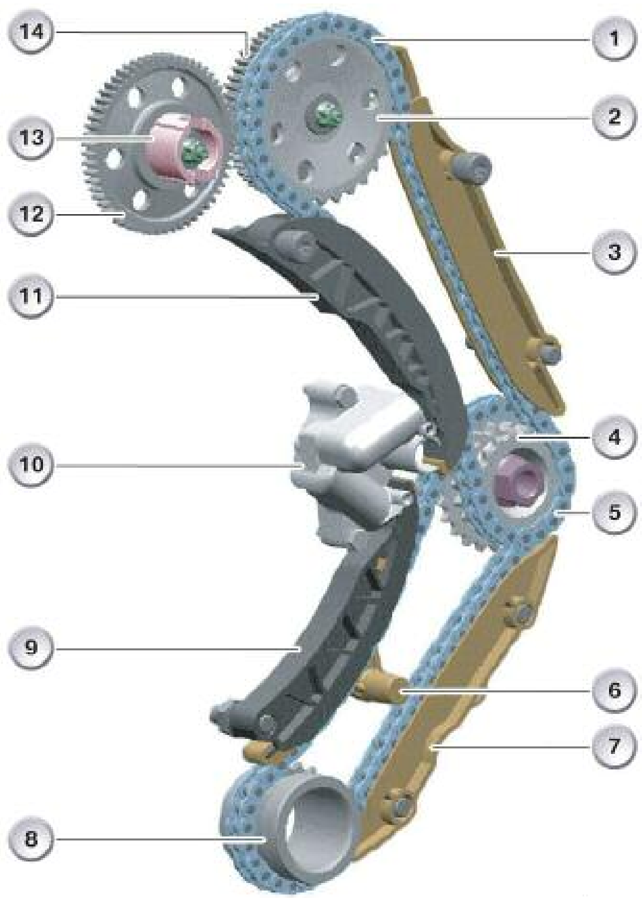
These adaptations are restricted to different coatings and materials on the inside.

Common Rail System Components

High Pressure Fuel Pump

The fuel pump used on common rail systems is a radial, piston type pump containing three pistons. The pump is mechanically driven via the engine timing chain. It is a volume controlled high pressure pump commonly known as the CP3.2+ (Bosch).

The delivery volume for this design is 866 mm^3, which is greater than the previous generation (CP 3.2).



Index	Explanation	Index	Explanation
1	Secondary chain	8	Sprocket, crankshaft
2	Sprocket, intake camshaft	9	Primary tensioning rail
3	Secondary guide rail	10	Hydraulic chain tensioner
4	Sprocket, high pressure pump	11	Secondary tensioning rail
5	Primary chain	12	Spur gear, exhaust camshaft
6	Oil spray nozzle	13	Dog coupling
7	Primary guide rail	14	Spur gear, intake camshaft

Functional Principle

The electric fuel pump supplies fuel to the high pressure pump via the feed line (1). The high pressure pump consists of three pistons that are raised by a common triple cam (7). Springs press the pistons against the drive cam.

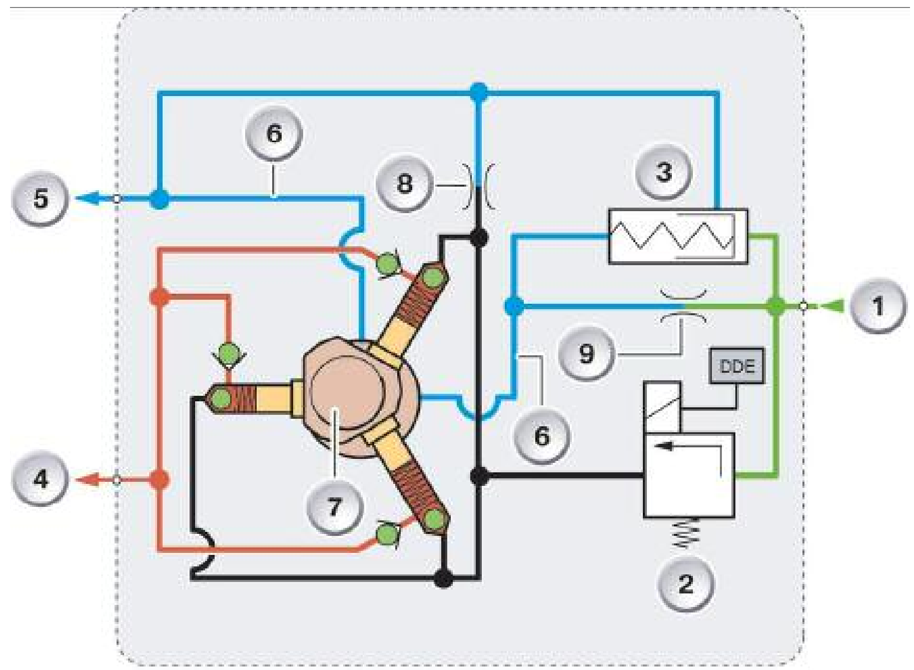
Each cylinder of the high pressure pump features ball valves for fuel inlet and outlet. The volume of fuel calculated by the DDE flows via the volume control valve (2) into the cylinders of the high pressure pump.

During the downward stroke of the pistons, the fuel flows from the volume control valve into the cylinders of the high pressure pump. Due to the downward movement of the pistons, the fuel is delivered at high pressure into the rail (4).

The drive cam is lubricated by the diesel fuel. For lubrication purposes, a quantity of the fuel flows from the feed (1) via throttle (9) and line (6) to the drive cam and from here into the return (5) of the high pressure pump.

An overflow valve (3) is integrated in the high pressure pump. The fuel now released for delivery by the volume control valve flows via the overflow valve into the return of the high pressure pump.

A small quantity of fuel can leak out of the closed volume control valve. To ensure this leakage fuel does not reach the main fuel delivery, it is routed via the zero delivery restrictor (8) into the return flow (5).



Index	Explanation	Index	Explanation
1	Feed	6	Line for lubricating drive cam and leakage oil return
2	Volume control valve	7	Drive cam
3	Overflow valve	8	Zero delivery restrictor
4	High pressure connection to rail	9	Throttle (restriction) for drive cam lubrication
5	Return		

Two-actuator Concept

In the first-generation common-rail system, rail pressure is controlled by a pressure control valve at the high-pressure pump. The CP always delivers fuel at the maximum rate, irrespective of the engine's operating condition. The fuel is heated on account of the high pressure produced by the pump running continuously at its maximum delivery rate. The fuel releases the energy gained in this way in the form of heat in a heat exchanger in the fuel return line.

The two-actuator concept consists of a volumetric fuel control in the line in front of the CP 3.2 and a fuel pressure regulator downline from the pump, at the rail.

Pressure in the rail is controlled by the pressure control valve only during starting and when the coolant temperature is below 19°C. Under these conditions volumetric fuel control is inactive.

In all other operating ranges volumetric fuel control is implemented by the flow regulating valve at the high-pressure pump. Pressure control by the pressure control valve is inactive.

The flow regulating valve on the intake side of the high pressure pump (CP 3.2 plus) is actuated by the DDE control unit. The flow regulating valve controls the pump delivery rate in such a way that only the volume of fuel actually required is supplied to the pump.

The quantity of excess fuel diminishes accordingly, so significantly less heat is generated in the fuel system.

There are many advantages deriving from volumetric fuel control:

- Lower manufacturing costs, because there is no need for a fuel cooler
- Improvements in efficiency and consumption because of the lower power requirement of the common-rail pump
- Optimum combustion and low raw emissions

The two-actuator concept therefore ensures an optimum fuel supply in all operating conditions.

Advantages

It can take up to 3-4 kW (4-5 HP) to drive the high pressure pump. This can result in a loss in fuel economy and engine power.
By using the two-actuator method of fuel control, the power requirement of the high pressure pump can be reduced in the partial load range of the engine, thus achieving a reduction in fuel consumption of up to 6% depending on the operating point of the engine.

The associated lower heating of the fuel in connection with pressure generation renders the fuel cooler in the engine compartment unnecessary.

Rail Pressure Sensor

The rail pressure sensor is located on the front of the fuel rail.
It measures the current pressure in the rail and sends a voltage signal, corresponding to the applied pressure, to the DDE.

The rail pressure sensor and the pressure control valve are adapted to the pressure ranges of the 3nd generation common rail system.

Pressure Control Valve

The pressure control valve is located at the rear of the rail.

The purpose of the pressure control valve is to control the pressure in the rail while starting the engine and when the coolant temperature is below 19°C.

It is actuated by the DDE control unit. The pressure control valve is additionally actuated while coasting to facilitate rapid pressure reduction.

Accumulator (Fuel Rail)

The accumulator (fuel rail) is mounted on the cylinder head and carries the rail-pressure sensor and the pressure control valve. The fuel rail is designed to retain fuel at very high pressure and store the required fuel volume to dampen pressure fluctuations from the high pressure pump.

This arrangement ensures that when the injectors open and close, the rail pressure remains constant. The fuel rail also provides connections for the high pressure lines to the injectors.

High Pressure Fuel Lines

The high pressure fuel lines provide the connection between fuel rail and fuel injectors as well as the connection between the high pressure pump and fuel rail.

The lines must be able to withstand the high pressures and the continuous pressure pulses in the common rail system.

It is essential to avoid over-torquing the lines, a loss of engine power could result from the reduction in fuel flow.

Fuel Injectors

The piezo-technology offers the following advantages:

- Nozzle needle movement twice as fast
- Switching times 5 times faster with very short dead time
- More effective metering of multiple injection
- High lift accuracy
- Lower hydraulic and electrical power requirements
- Compact design
- Moved mass reduced by 75%
- Weight reduced by 33%
- Possible to increase rail pressure to 1800 bar.

These advantages are reflected in distinct improvements regarding pollutant emissions, fuel consumption and acoustics.

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.

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).

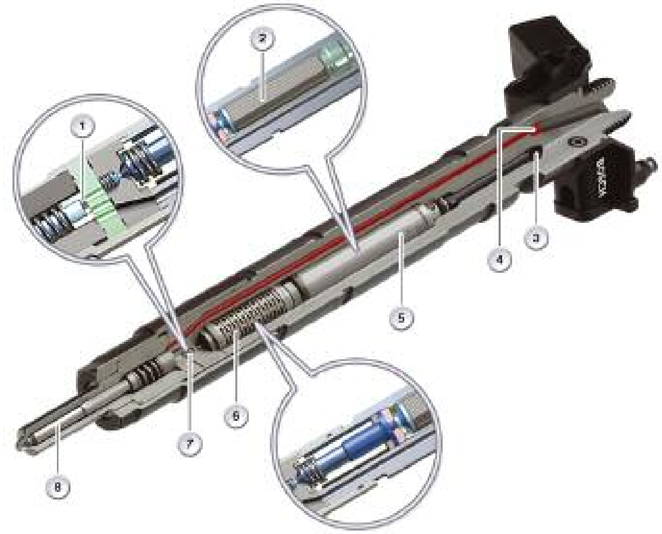
Instead, the piezo element is used to trigger a relay valve in the actuator module. The injector is then hydraulically "imbalanced" which causes the pintle to open via the fuel rail pressure.

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.



Index	Explanation
1	Control chamber
2	Piezo element
3	Hydraulic return
4	Hydraulic inlet
5	Actuator module
6	Coupler module
7	Shift valve
8	Nozzle needle

Piezo-Electric Principles

Up until now, the most familiar application of piezo technology in automobiles has been the knock sensor. The knock sensor (KS) consists of piezo electric crystals which generate a voltage when a force is exerted. When an engine knock occurs, the resulting vibration acts upon the piezo crystals in the knock sensor. A voltage is generated and sent to the engine management to indicate the presence of engine knock.

Taking what is known about knock sensors, the piezo injector uses the “inverse” method. When a voltage is applied to the piezo crystal, the crystal expands by a specified amount. By stacking the piezo elements, the required amount of movement can be obtained.

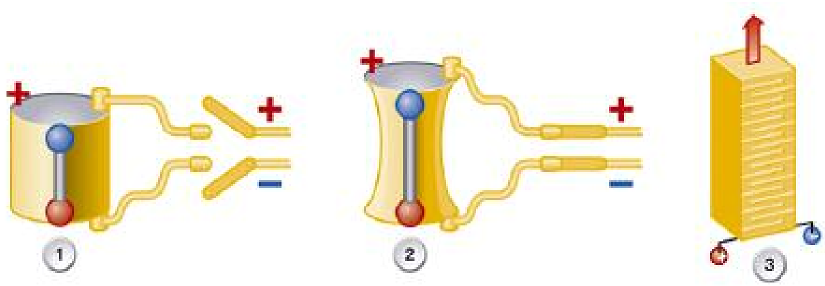
The new fuel injector design uses a piezo-ceramic elements and an electro-mechanical converter. This “inverse piezoelectric effect” is now used to convert electrical signals into mechanical movement.

Piezo Technology

Some of the first discoveries in piezoelectric technology were as early as the 1880’s. Among the early pioneers in this area was Pierre and Jacques Curie. It was discovered that certain naturally occurring crystals (such as quartz and topaz) exhibited surfaces charges when subjected to external forces.

Since then, there have been numerous advances in this area. Modern day applications of piezoelectric technology include microphones and phonographic needles. Various automotive applications include knock sensors, pressure sensors and acceleration sensors.

Today, many present day sensors include man-made piezo electric materials such as piezo-ceramic and piezo-resistive materials. Most modern day vehicles utilize a variety of piezo-electric devices in one or more vehicle systems.



Index	Explanation
1	Piezo element with no voltage applied
2	Piezo element with no voltage applied
3	Piezo element (layers) with voltage applied

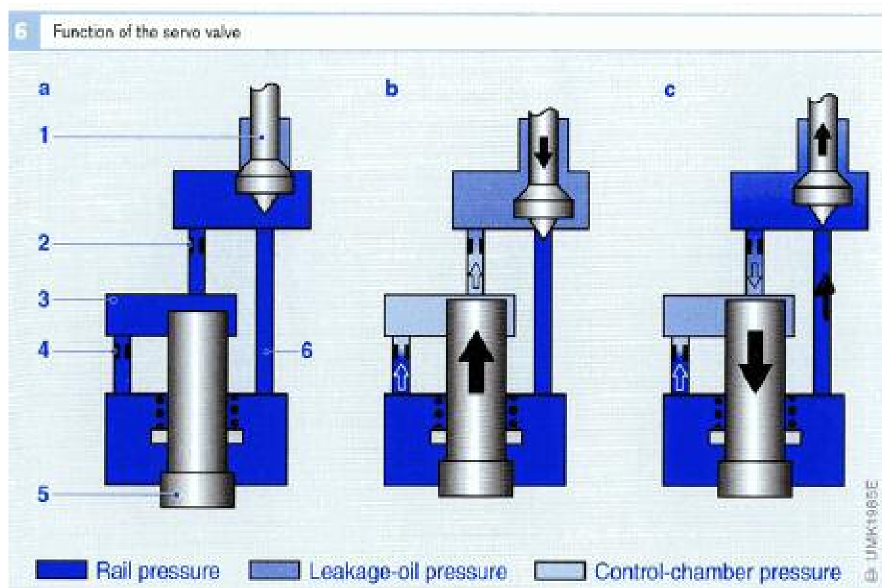


Fig. 6
- a Start position
- b Nozzle needle opens (bypass closed, normal function with outlet and inlet restrictors)
- c Nozzle needle closes (bypass open, function with two inlet restrictors)

1. Servo valve (control valve)
2. Outlet restrictor
3. Control chamber
4. Inlet restrictor
5. Nozzle needle
6. Bypass

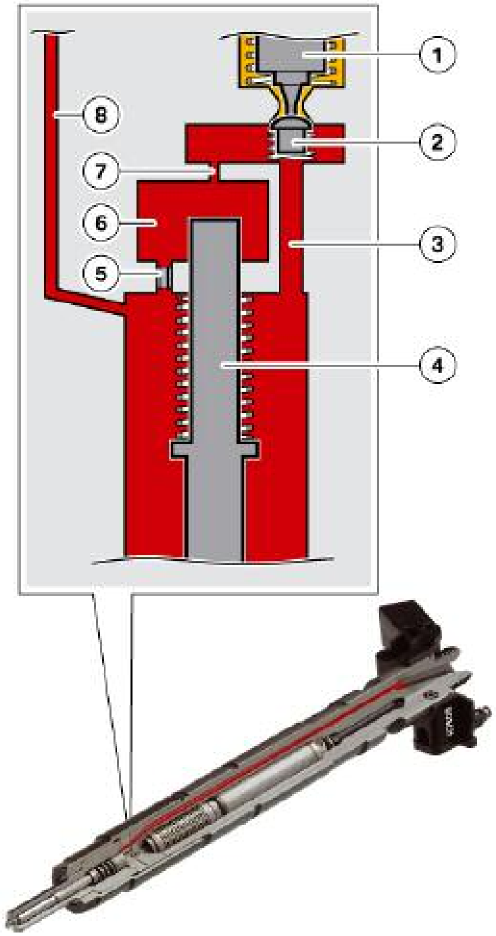
Fuel Injector Operation

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

When the injector is controlled, the actuator module expands. This movement is transferred to the switch valve by the coupler module. When the switch valve opens, the pressure in the control chamber drops and the nozzle needle opens in exactly the same way as with the solenoid valve injector.

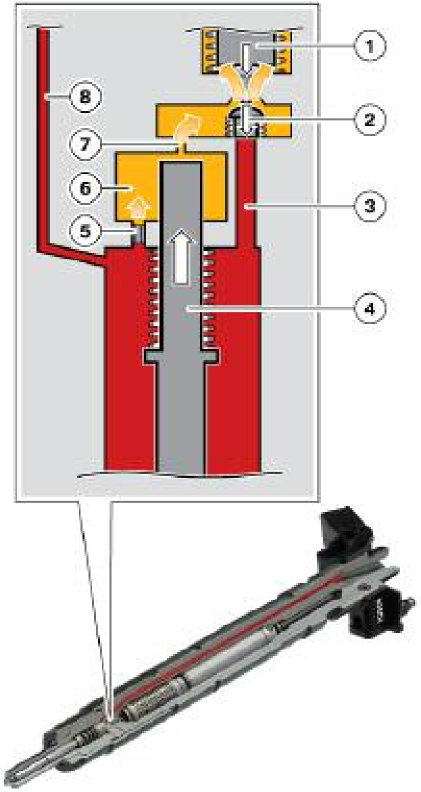
The benefits of the PIEZO injector are that they offer a considerably faster control response, which results in greater metering accuracy.

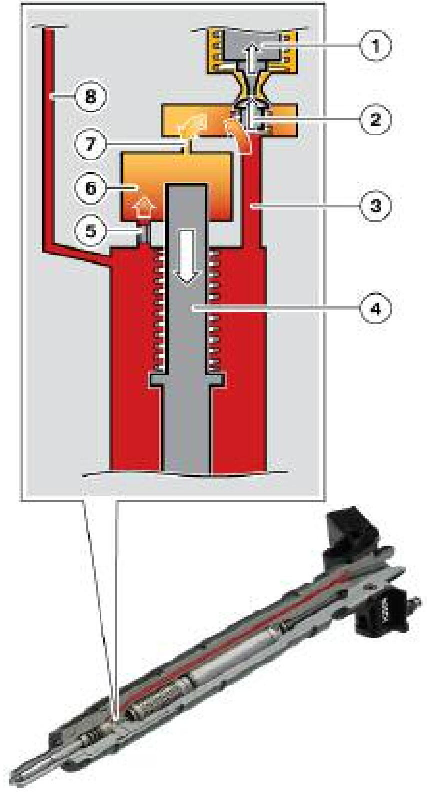
In addition, the PIEZO injector is smaller, lighter and has a lower power consumption. The M57D30T2 engine is equipped with PIEZO injectors that have been developed further still and are even more compact and lighter.



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

Piezo Injector Operation





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.

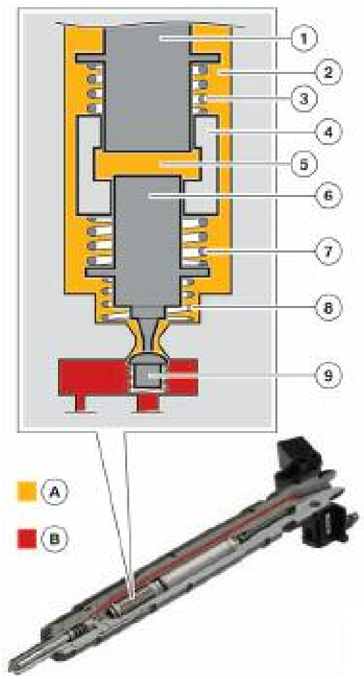
Coupler Module

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

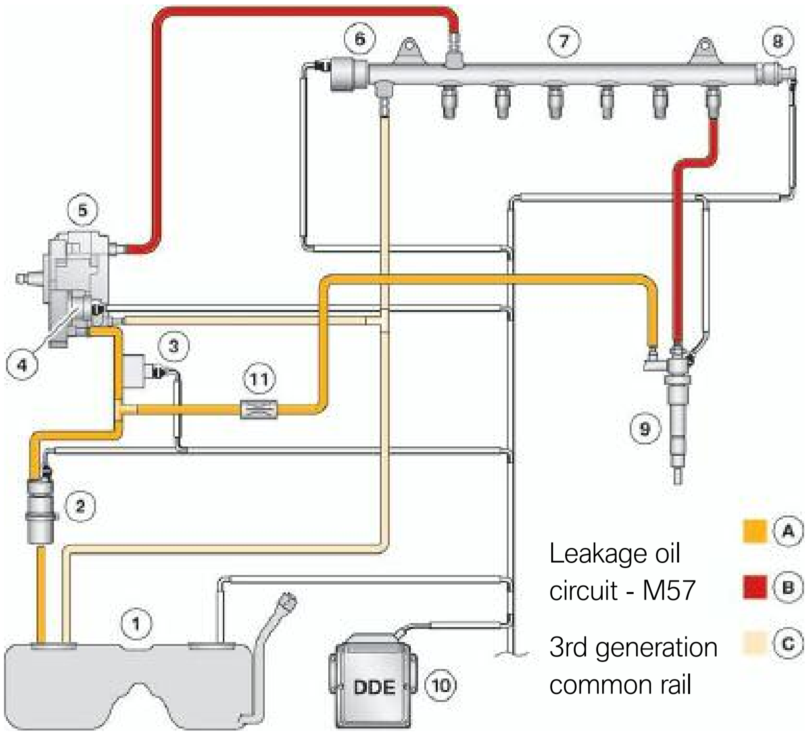
The piezo injectors require a certain amount of backpressure in the leakage circuit in order to operate properly. So, the leakage circuit on the 3rd generation common rail differs from the earlier versions.

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.

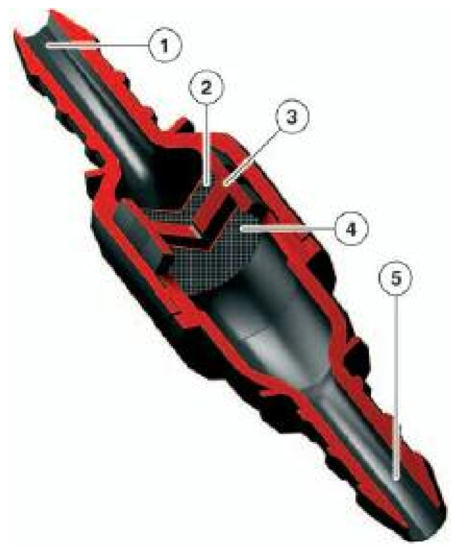
In order to maintain this pressure, a restrictor (11) has been installed between the injector(s) and the low pressure feed to the HP pump.



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.

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Air Intake System

In addition to reducing the intake noise, the air intake system ensures an optimum supply of fresh air to the combustion chamber. A wave of negative pressure acting against the direction of flow of the fresh air intake is created by the movement of the piston after opening the intake valve.

The resulting pressure fluctuations are radiated in the form of sound via the mouth of the intake system. In addition, the pulsation that occurs inside the air intake system causes the walls of the components to vibrate, thus also radiating noise. The air intake system is therefore optimized in such a way that no disturbing or annoying vibration can occur thus conforming to the noise emission limits applicable worldwide.

The intake system can be divided into two sections. The intake snorkel, intercooler and, with exceptions, the intake silencer are specifically assigned to the vehicle and differ even in connection with the same type of engine due to the different characteristics of the vehicle models.

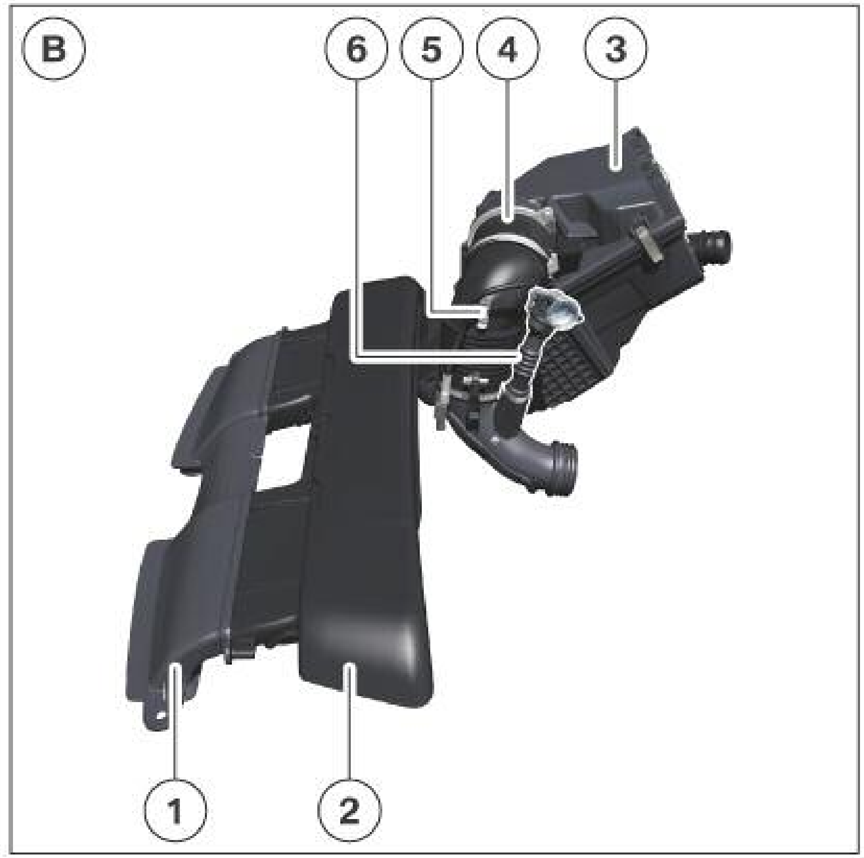
The exhaust turbocharger and the intake system with swirl flaps, throttle valve and various sensors are assigned to the engine.

Apart from the exhaust turbocharger and exhaust manifold, the exhaust system is designed vehicle-specific and differs depending on the type of vehicle and specification.

Note: If the filtered air pipe downstream of the blow-by gas connection is heavily oiled, this could imply increased blow-by gas levels. The cause of this is usually a leak in the engine (e.g. crankshaft seal) or surplus air taken in through the vacuum lines.

A consequential symptom would then be an oily exhaust turbocharger, which does not mean that there is a fault with the exhaust turbocharger itself.

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

Intake Silencer/Air Filter

The intake silencer houses the filter element and is designed such that the filter element has as long a service life as possible.
The larger the filter element, the longer the service life and also the greater the space requirement.

The housing of the intake silencer is also designed to deform in the event of impact from above (pedestrian collision). This means that it compresses by several centimeters.

M57D30T2 Engine

Due to space restrictions on twin turbo engines, the intake silencer is not fitted directly on the engine. In this case, the intake silencer is positioned laterally on the wheel well.

The intake silencer reduces the intake noise and houses the filter element.

Unfiltered Air Duct

The unfiltered air duct consists of the unfiltered air snorkel, pipe and the unfiltered air area of the intake silencer. The unfiltered air snorkel and pipe are designed with the crash safety of pedestrians in mind. This entails the use of especially soft materials and yielding connections.

The M57D30T2 engine draws in the unfiltered air laterally behind the bumper ahead of the cooling module. The unfiltered air is routed via coarse-mesh screen (1) via unfiltered air snorkel (2) and unfiltered air pipe (3) into the unfiltered air area of intake silencer (4).

The coarse-mesh screen prevents large particles such as leaves from being drawn in. The unfiltered air snorkel in the M57 engine is designed as an unfiltered air intake shroud. This has a large surface area, but is exceptionally flat. The air is drawn in by the cooling module.

Intercooler

The temperature of the air increases as the air is compressed in the exhaust turbocharger. This causes the air to expand. This effect undermines the benefits of the exhaust turbocharger because less oxygen can be delivered to the combustion chamber.

The intercooler cools the compressed air, the air's density increases and thus more oxygen can be delivered to the combustion chamber.

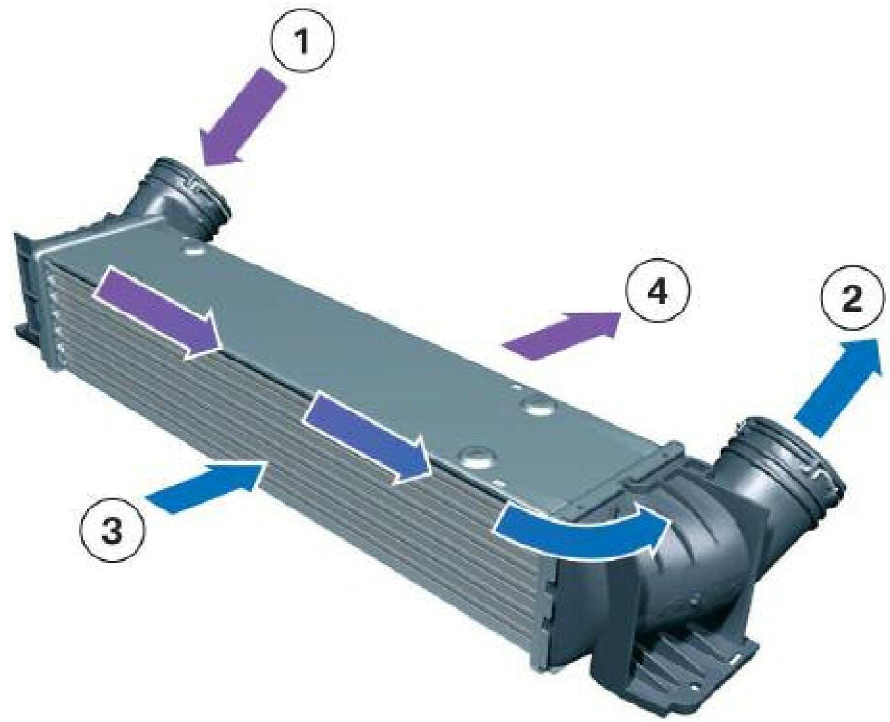
On BMW diesel engines, charge air is cooled exclusively by fresh air with an air-to-air heat exchanger. The charge air cooling rate greatly depends on the vehicle speed, temperature of the incoming fresh air and the design of the intercooler.

The main purpose of turbocharging in a diesel engine is to boost output. Since more air is delivered to the combustion chamber as a consequence of "forced aspiration", it is also possible to have more fuel injected, which leads to high output yields.

However, the air density and therefore the mass of oxygen that can be delivered to the combustion chamber is reduced because the air heats up, and thus expands, as it is compressed.

The intercooler counteracts this effect because the cooling process increases the density of the compressed air, i.e. so too the oxygen content per volume.

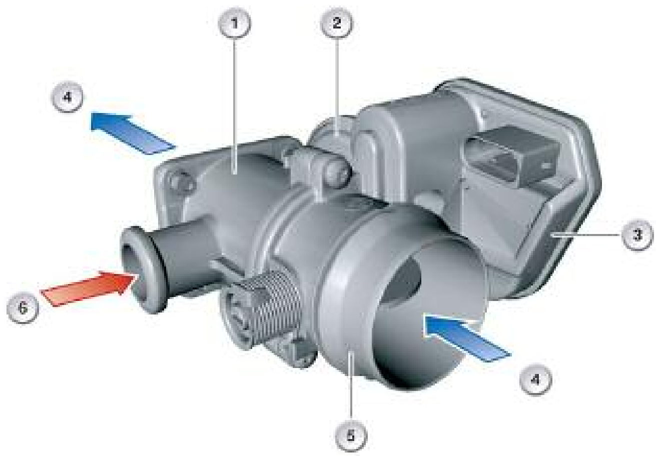
As a result, a larger volume of fuel-air mixture can be combusted and converted into mechanical energy. The intercooler is responsible for reduced intake air temperatures compared to a vehicle with no intercooler. This means the power output can be additionally increased as a larger mass of air can be conveyed into the combustion chamber.



Index	Explanation
1	Heated charge air
2	Cooled charge air
3	Cooled fresh air
4	Heated fresh air

Throttle Valve

A throttle valve is required in all diesel engines, including those equipped with a diesel particulate filter. By throttling the intake air, the throttle valve ensures that the elevated exhaust gas temperatures required for diesel particulate filter regeneration are achieved.



Index	Explanation
1	Throttle housing
2	EGR vacuum diaphragm
3	Throttle motor with feedback electronics
4	Incoming air
5	Charge air hose connection from intercooler
6	EGR connection

The throttle valve is closed when the engine is shut down to avoid engine shudder. After the engine has stopped, the throttle valve is reopened.

The throttle valve also serves the additional function of effectively preventing over-revving of the engine. If the DDE detects over-revving without an increase in the injection volume, the throttle valve will close in order to limit the engine speed.

This situation can occur as the result of combustible substances entering the combustion chamber. Substances may be engine oil from an exhaust turbocharger with bearing damage. This function can effectively prevent major damage to the engine. The throttle valve is located directly upstream of the intake manifold.

The DDE calculates the position of the throttle valve from the position of the accelerator pedal and from the torque requirement of other control units. The DDE controls actuation of the throttle valve by means of a PWM signal with a pulse duty factor of 5 to 95%.

To achieve optimum control of the throttle valve, its exact position must be recorded on a continual basis. The throttle valve position is monitored contactlessly in the throttle valve actuator by 2 Hall sensors. The sensors are supplied with a 5 V voltage and connected to ground by the DDE. Two data lines guarantee redundant feedback of the throttle valve position to the DDE.

The second signal is output as the inverse of the first. The DDE evaluates the plausibility of the signal through subtraction.

The actuator motor for operating the throttle valve is designed as a DC motor. It is driven by the DDE on demand. An H-bridge is used for activation which makes it possible to drive the motor in the opposite direction. The H-bridge in the DDE is monitored by the diagnostics system.

When no power is applied to the drive unit, the throttle valve is set, spring-loaded, to an emergency operation position.

The throttle valve is required for regenerating the diesel particulate filter in order to increase the exhaust temperature by intervening in the air-fuel mixture. In addition, the throttle valve is closed when the engine is shut down in order to reduce shut-down shudder.

The throttle valve also effectively prevents over-revving of the engine.

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Swirl Flaps

The US version of the M57 engine utilizes swirl flaps which are located in the intake manifold. The swirl flaps are controlled electrically. This method of actuation 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.

Swirl flaps ensure better swirl of the incoming air during the intake and compression cycles. This method of air control works in conjunction with the piston geometry to ensure more complete mixture formation.

By controlling "swirl" within the combustion chamber, significant reductions in NOx and particulate emissions are possible.

The adjustable swirl flaps are located in the tangential channels of the intake system and are opened and closed according to the operating status of the engine.

On the M57TU engine, the swirl flaps are closed at low RPM and load conditions. To increase the swirl effect, swirl flaps are designed to close tightly on the M57TU engines.

Swirl Flap Operation

Swirl flap (4) closes tangential port (3) to achieve greater turbulence of the air via swirl port (2) in the combustion chamber at low engine speeds. With increasing engine speed, it opens to facilitate charging through the tangential ports.

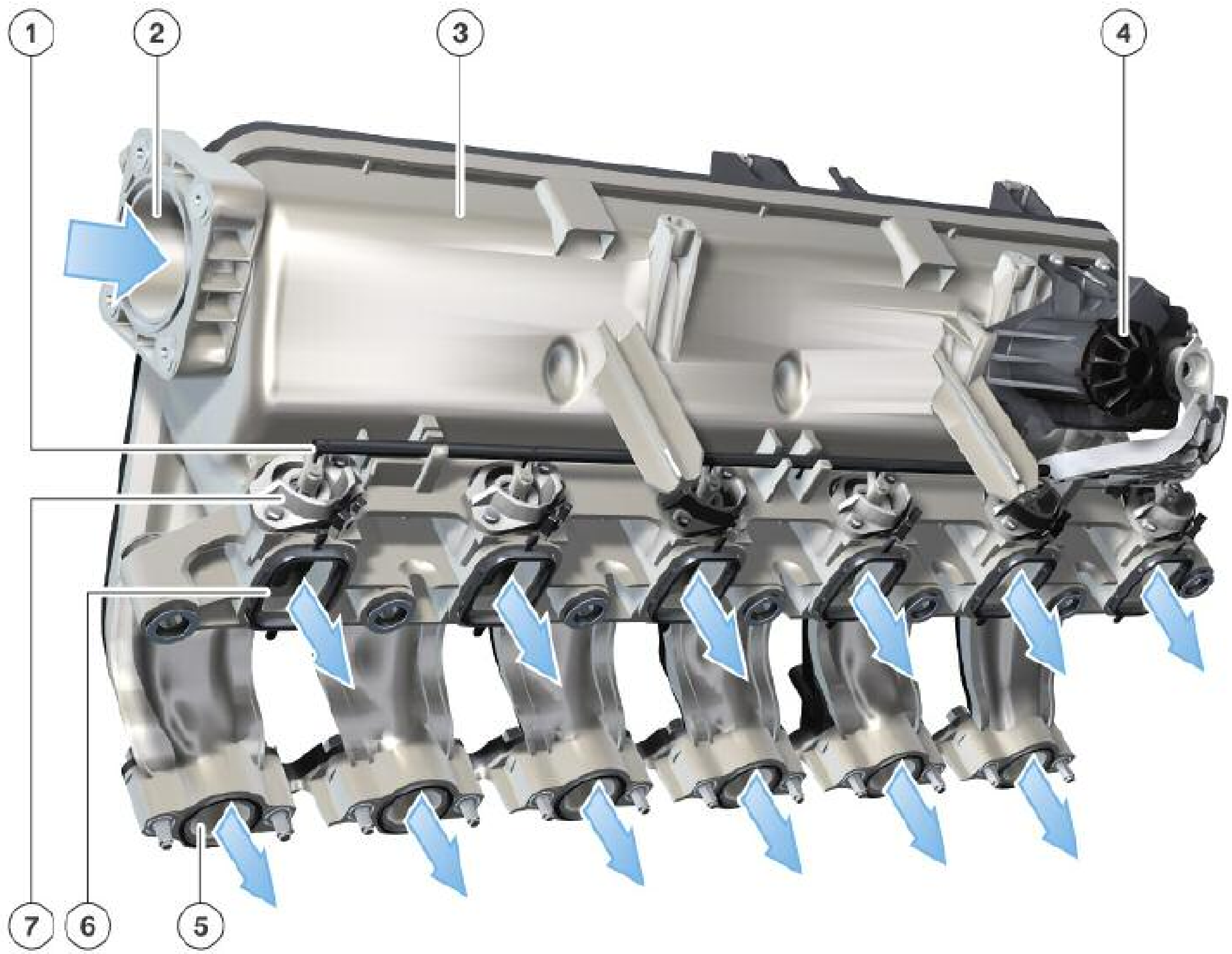
The position is based on the driver's load choice, engine speed and the coolant temperature.

The swirl flaps are varied by a linkage (1) that is operated by a DC motor..

Effects of Swirl Flap Malfunctions

If the swirl flaps stick in open position: Deterioration in exhaust gas characteristics in lower speed ranges otherwise no effect.

If the swirl flaps stick in closed position: Power loss of approximately 10% at higher engine speeds.

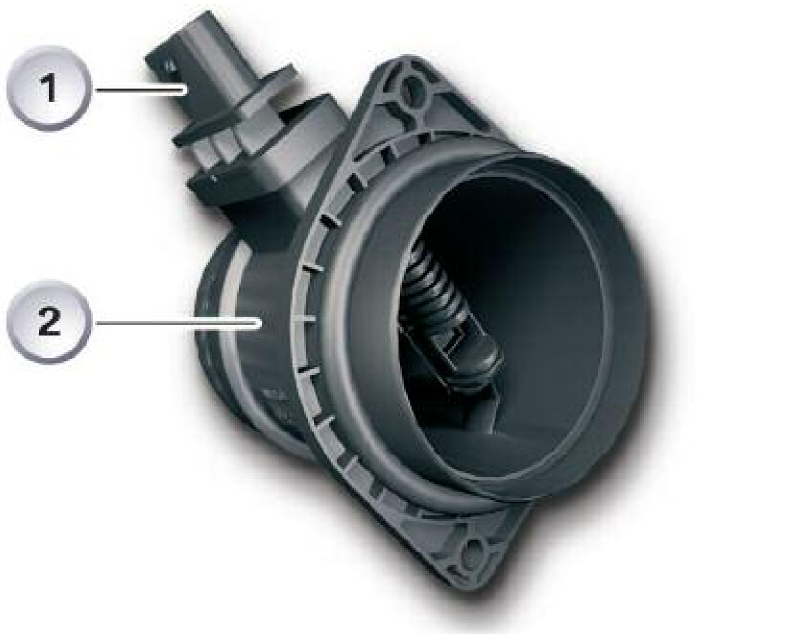


Index	Explanation	Index	Explanation
1	Control rod for swirl flaps	5	Swirl ports
2	Throttle plate mounting	6	Tangential ports
3	Intake manifold	7	Swirl flaps
4	Electric motor (for swirl flaps)		

Hot-film Air Mass Meter (HFM 6.4)

The hot-film air mass meter HFM 6.4 is used together with DDE on the M57TU. The HFM 6.4 is designed for an air throughput rate of up to 640 kg air/h.

The HFM 6.4 measures the air mass intake within very close tolerances so as to permit precise control of the exhaust gas recirculation as well as optimum configuration of the smoke limit. This is important for complying with current and future emission limits.



Index	Explanation
1	Connector
2	Housing

Functional Principle

The principle design of the HFM 6.4 corresponds to that of the HFM 5 previously used. The hot-film air mass meter HFM 6.4 is powered with system voltage.

A new feature is that the sensor signal is digitized already in the HFM 6.4. The digitized signal is transferred frequency-modulated to the DDE.

In order to be able to compensate for the temperature influences, the air mass signal is referred to the changing temperature signal.

The HFM 6 hot-film air mass meter is located downstream of the intake silencer and is fitted directly to its cover. The HFM measures the air mass taken in by the engine. This is used to record the actual air mass, which in turn is used to calculate the exhaust gas recirculation rate and the fuel limit volume.

There is also an intake air temperature sensor located in the HFM housing. The temperature is evaluated by the HFM and sent to the DDE as a PWM signal.

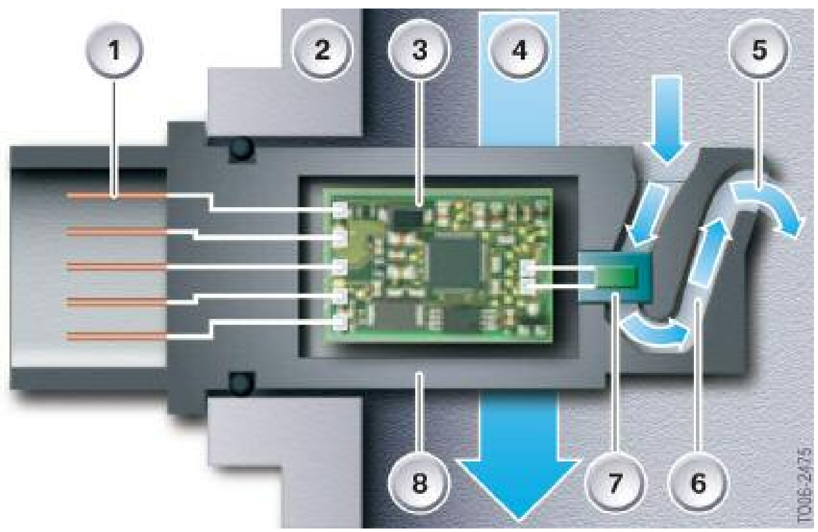
A pulse width of 22% equates to a temperature of -20°C and a pulse width of 63% equates to a temperature of 80°C.

Measurement Method

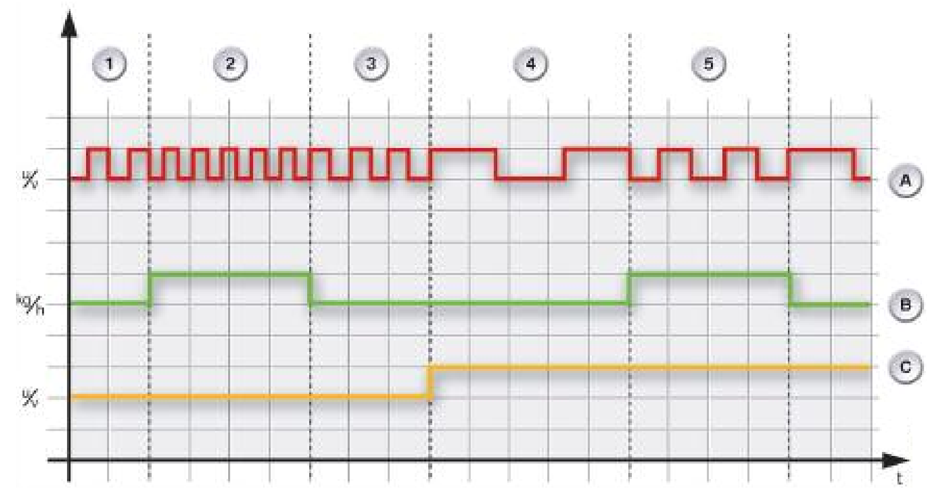
A labyrinth (6) makes sure that only the actual air mass is recorded. Thanks to the labyrinth, backflow and pulsation are not registered. In this way, the HFM determines the actual air mass irrespective of the air pressure and backflow.

An electrically heated sensor measuring cell (7) protrudes into the air flow (4). The sensor measuring cell is always kept at a constant temperature. The air flow absorbs air from the measuring cell. The greater the mass air flow, the more energy is required to keep the temperature of the measuring cell constant.

The evaluator electronics (3) digitizes the sensor signals. This digitized sensor signal is then transferred frequency-modulated to the DDE. In order to be able to compensate for temperature influences, the air mass signal is referred to the variable temperature signal.



Index	Explanation
1	Electric connections
2	Measurement tube housing
3	Electronic evaluator
4	Mass air flow
5	Partial flow for measurement,exhaust
6	Labyrinth
7	Sensor measuring cell
8	Sensor housing



Index	Explanation
A	Air mass signal
B	Air mass
C	Temperature signal
1	Air mass signal (A) as a function of air mass (B) and temperature signal (C)
2	The period duration of the air mass signal (A) decreases as the air mass (B) increases
3	The period duration of the air mass signal (A) is extended as the air mass (B) reduces
4	When the temperature increases (C) and air mass (B) remains constant, the period duration of the air mass signal (A) is extended in order to compensate for temperature influences
5	When air mass (B) increases, the period duration of the air mass signal decreases while taking the temperature signal (C) into account

Charge Air Temperature Sensor

The charge-air temperature sensor records the temperature of the compressed fresh air. It is located in the boost-pressure pipe, directly upstream of the throttle valve.

The charge-air temperature is used as a substitute value for calculating the air mass. This is used to check the plausibility of the value of the HFM. If the HFM fails, the substitute value is used to calculate the fuel flow measurement and the EGR rate.

The DDE connects the intake temperature sensor to ground. A further connection is connected to a voltage divider circuit in the DDE.

The intake temperature sensor contains a temperature-dependent resistor that protrudes into the flow of intake air and assumes the temperature of the intake air.

The resistor has a negative temperature coefficient (NTC). This means that the resistance decreases as temperature increases.

The resistor is part of a voltage divider circuit that receives a 5 V voltage from the DDE. The electrical voltage at the resistor is dependent on the air temperature. There is a table stored in the DDE that specifies the corresponding temperature for each voltage value; the table is therefore a solution to compensate for the non-linear relationship between voltage and temperature.

The resistance changes in relation to temperature from about 75 k Ohms to 87 Ohms, corresponding to a temperature of -40°C to 120°C.

Boost Pressure Sensor

The boost pressure sensor is required for boost pressure control. The boost pressure sensor monitors and controls the boost pressure in accordance with a characteristic map resident in the DDE.

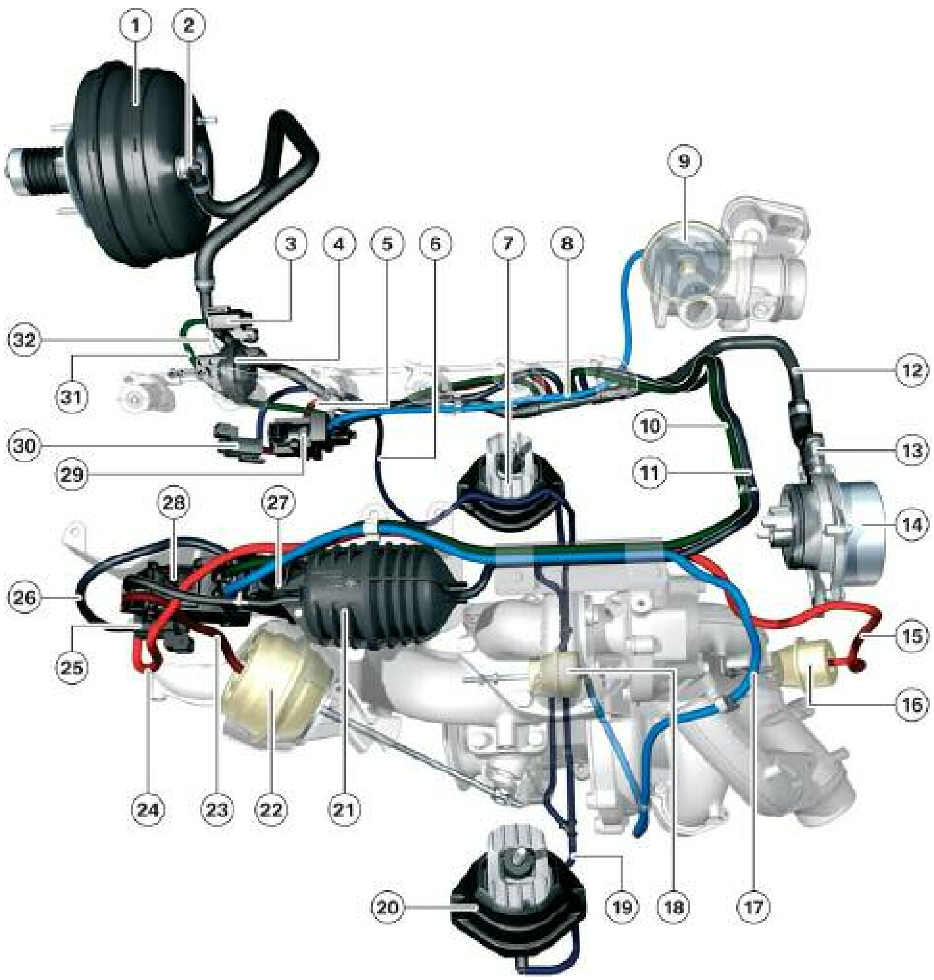
The boost pressure is also used for calculating the volume of fuel. The sensor is supplied with a 5 V voltage and connected to ground by the DDE. The information is sent to the DDE on a signal line.

The evaluation signal fluctuates depending on the pressure. On the M57D30T2 engine, the measuring range from approximately 0.1 - 0.74 V corresponds to an absolute pressure from 50 kPa (0.5 bar) to 330 kPa (3.3 bar).

Vacuum System

On the diesel engine, numerous Vacuum operated devices are used to control EGR, turbocharging and motor mounts.

To simplify assignment, the vacuum lines from several valves to the vacuum units are marked in color. This color code is also used for the actual components.



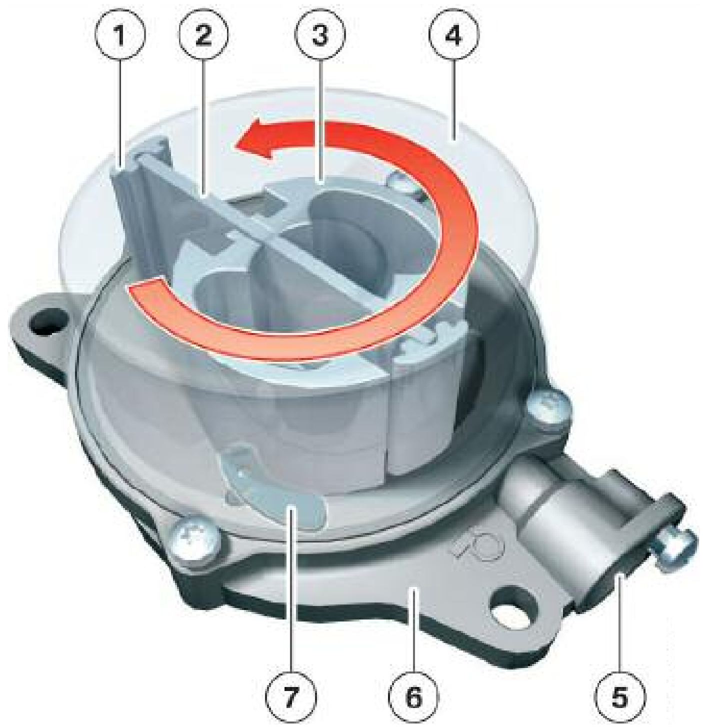
ECE Version

Index	Explanation	Index	Explanation
1	Brake booster	17	Vacuum line, EPDW wastegate
2	Non-Return valve	18	Vacuum unit for wastegate
3	EUV Swirl flaps	19	Vacuum line, EUV engine mount
4	Vacuum unit for swirl flaps	20	Engine mount
5	Vacuum line, EUV engine mount	21	Vacuum reservoir
6	Vacuum line, engine mount	22	Vacuum unit, EPDW turbine control valve
7	Variable engine mount	23	Vacuum line, EPDW turbine control valve
8	Vacuum Distributor	24	Vacuum line, EUV compressor bypass valve
9	Vacuum unit for EGR valve (not US)	25	EUV compressor bypass valve
10	Vacuum line, EDPW wastegate	26	Vacuum line, EUV compressor bypass valve
11	Vacuum line, Vacuum reservoir	27	EPDW wastegate
12	Vacuum line brake booster	28	EPDW turbine control valve
13	Non-Return valve	29	EPDW EGR valve
14	Vacuum pump	30	EUV engine mount
15	Vacuum line, EUV compressor bypass valve	31	Vacuum line swirl flaps (not US)
16	Vacuum unit for compressor bypass valve	32	Vacuum line, EUV swirl flaps (not US)

Component	Color
Wastegate	Blue
Compressor bypass valve	Red
Turbine control valve	Black
EGR Valve (not US)	Blue
Engine mount	Black/Red
Swirl flaps (not US)	White

Vacuum Pump

The vacuum pump is driven by the exhaust camshaft that is connected to rotor (3) by means of a jaw clutch. While the engine is running, sliding blocks (1) run against housing cover (4).



Index	Explanation
1	Sliding block
2	Slide valve
3	Rotor
4	Housing cover
5	Vacuum connection
6	Housing
7	Non-return valve

The engine oil lubrication system provides a seal to the two different chambers on both sides of slide valve (2). The air is drawn in via vacuum connection (5) on the right-hand side and delivered to the engine via non-return valve (7) on the left-hand side.

The vacuum pump has a volume of 0.15 liters. Evacuation of the vacuum system to a vacuum (negative pressure) of 500 mbar (absolute) (depending on type of engine) takes place in less than 5 seconds at an engine speed of approximately 720 rpm.

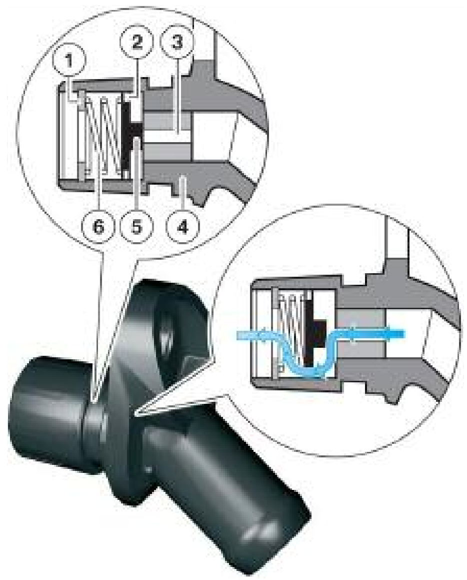
The volume to be evacuated amounts to approximately 4.2 liters.

Non-return Valve

The non-return valve prevents vacuum escaping via the vacuum pump when the engine is not running.

Retaining ring (1) supports spring (6). The other end of the spring presses seal (5) against hole (3). The vacuum built up in the hole and in the vacuum system firmly sucks the seal onto the hole, ensuring no vacuum can escape via the vacuum pump. The seal is forced against the spring while the vacuum pump is in operation thus releasing the hole.

Air can now be drawn in via the hole and openings (2) in the seal.

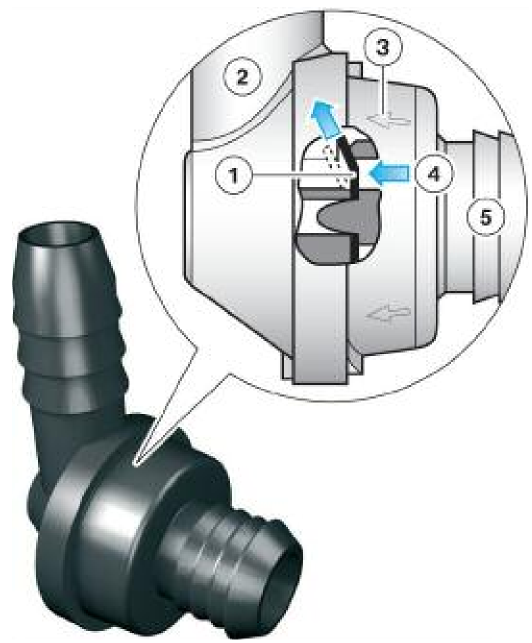


Index	Explanation
1	Retaining ring
2	Opening
3	Hole
4	Housing
5	Seal
6	Spring

Non-return Valve, Brake Booster

The non-return valve prevents vacuum escaping from the brake booster when the engine is not running.

From the vacuum connection to vacuum pump (2), the air is drawn out of the brake booster via valve plate (1) above the brake booster vacuum connection. To prevent incorrect installation, direction arrows (3) indicate the direction of flow (4).



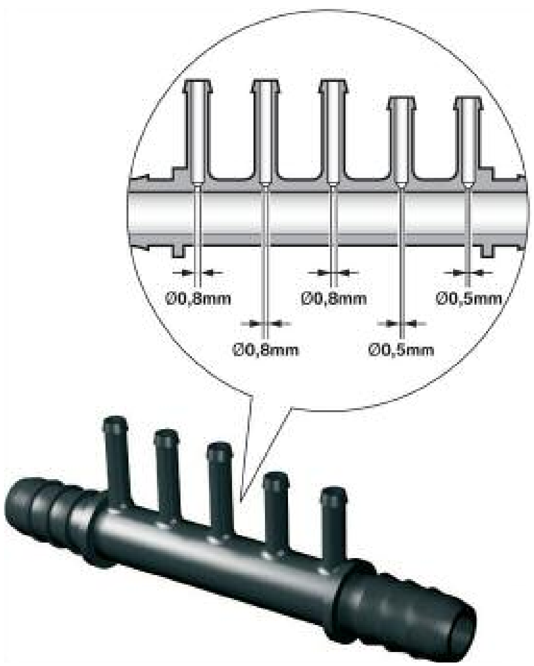
Index	Explanation
1	Valve plate
2	Vacuum connection to vacuum pump
3	Direction arrow
4	Direction of flow
5	Vacuum connection, brake booster

Vacuum Distributor

The task of the vacuum distributor is to distribute the vacuum via lines to various system. Different sized apertures (orifice) are built into the connections of the vacuum distributor.

This makes sure that the majority of the vacuum is always available for power assisted braking. Unused connections are closed off with a rubber cap.

A distributor with five connections is used on the M57D30T2 engine.



Connection	Orifice Size
Wastegate	0.8 mm
Compressor bypass/Turbine control valve	0.8 mm
EGR Valve (not US)	0.8 mm
Engine mount	0.5 mm
Swirl flaps (not US)	0.5 mm

Vacuum Reservoir

The vacuum reservoir retains a defined vacuum for the purpose of making available vacuum to meet temporary increases in vacuum requirements.

For instance, on twin turbo engines this makes it possible to still control the turbine control valve and the compressor bypass valve in the event of the vacuum failing in the system. If this would not be possible, an immediate drop in engine output would be noticeable.

A situation in which such a failure in the vacuum system may occur is when the brake booster requires large quantities of vacuum.

For this purpose, the vacuum reservoir is equipped with a non-return valve that prevents the vacuum escaping in the direction of the brake booster.

If it were not for this vacuum reservoir, the vacuum pump would have to be built much larger so as to make available sufficient vacuum to control the turbocharger assembly while the brake booster is operating at maximum.

However, the capacity of such a pump would be fully utilized only very rarely. A vacuum reservoir therefore represents the most efficient option of covering maximum vacuum requirements.

Electro-pneumatic Pressure Converter (EPDW)

The Electro-pneumatic pressure converter is used for components that are activated infinitely variable with vacuum. The Electro-pneumatic pressure converter is able to mix the incoming vacuum with ambient air and set any required negative pressure (mixed pressure) between these two negative pressure levels.

The resulting negative pressure is then used as the control variable for actuating pneumatic components.

These components include:

- Low Pressure EGR
- Vacuum unit for turbine control valve
- Vacuum unit for wastegate

The vacuum (negative pressure) is applied at vacuum connection (1). The ambient pressure passes through filter element (3) into the valve. Vacuum connection outlet (2) may be marked in color (here blue) to prevent confusion with several components of the same type.

The mixed pressure is made available via the vacuum outlet. The mixed pressure is used to set infinitely variable any position between "open" and "closed".

The DDE actuates the Electro-pneumatic pressure converter pulse width modulated at approximately 300 Hz. The negative pressure at the vacuum outlet is infinitely variable depending on the pulse duty factor.

The pulse duty factor may be between 0 and 100%. The Electro-pneumatic pressure converter is closed at a pulse duty factor of 6% and ambient pressure is applied.

The Electro-pneumatic pressure converter is fully open at a pulse duty factor of 98% and the maximum vacuum of the vacuum system is applied.

Index	Explanation
1	Vacuum connection
2	Vacuum outlet
3	Filter element
4	Electric plug connection

Electric Changeover Valve (EUV)

The electric changeover valve is used for components that switch in two positions. The electric changeover valve makes it possible to switch either no vacuum or the maximum available vacuum from the vacuum connection (1) to vacuum outlet (2).

In contrast to the Electro-pneumatic pressure converter, here no mixed pressure is set but rather the vacuum in the system is switched through to the vacuum unit.

On the M57D30T2 engine, this electric changeover valve is used for the variable engine mounts and the compressor bypass valve.

The electric changeover valve is actuated by the DDE.

Index	Explanation
1	Vacuum connection
2	Vacuum outlet
3	Electric plug connection

Electrically Actuated (EL)

The components that are electrically actuated by the DDE include:

- Throttle Valve
- Swirl Flaps
- High Pressure EGR Valve
- SCR Metering Valve

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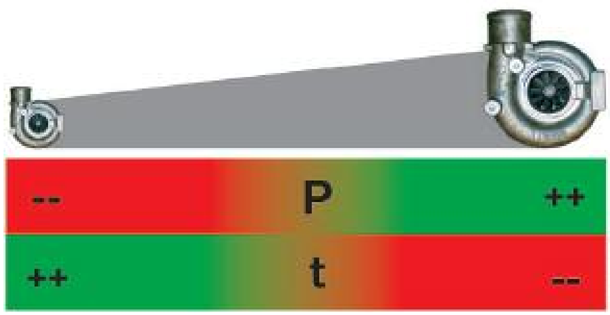
Exhaust Turbocharger

The turbocharger is driven by the engine's exhaust gases. The hot, pressurized exhaust gases are directed through the turbine of the exhaust turbocharger, thus producing the drive force for the compressor.



Index	Explanation
P	Engine output
t	Response characteristic

The intake air is pre-compressed so that a higher air mass enters the combustion chamber in the engine. In this way, it is possible to inject and combust a greater quantity of fuel, which increases the engine's power output and torque.

The speeds of the turbine are between 100,000 rpm and 200,000 rpm. The exhaust inlet temperature may be up to approximately 900°C.

The performance of a turbocharged engine can reach the levels achieved by a naturally aspirated engine with significantly more capacity. However, the boost effect can also be used in a small engine to achieve a certain output with comparatively reduced consumption.

Twin Turbocharging

Due to the operating principle as previously mentioned, the design of a turbocharger always involves a conflict of objectives.
A small exhaust turbocharger responds quickly and provides ample torque at low engine speeds. However, its power output is limited as it quickly reaches the surge and choke line. Although it can generate high pressures, the volumetric flow is limited due to its size.

A large exhaust turbocharger is capable of producing high power output levels at high engine speeds. However, it responds sluggishly and is not capable of generating a high boost pressure at low engine speeds.

The ideal solution would be to have two exhaust turbochargers. One small turbocharger for quick response and one large turbocharger for maximum output yield.

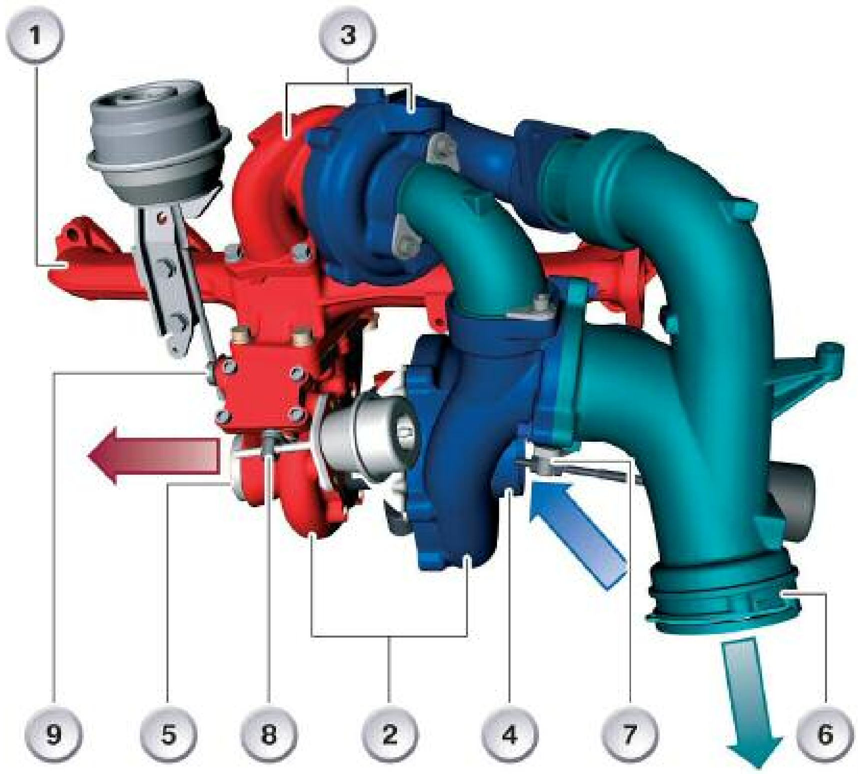
Precisely this configuration has now been developed for BMW twin turbo diesel engines. Two series-connected exhaust turbochargers are used.

A small turbocharger for the high pressure stage and a larger turbocharger for the low pressure stage. The two turbochargers do not have variable vanes.

The two turbochargers can be variably combined providing an optimum for the entire operating range. This interplay is made possible by various flaps and valves.

These are:

- Turbine control valve (exhaust side)
- Compressor bypass valve (air side)
- Wastegate (exhaust side)



Index	Explanation
1	Exhaust manifold
2	Exhaust turbocharger - low pressure stage (large turbo)
3	Exhaust turbocharger - high pressure stage (small turbo)
4	Intake air inlet from air cleaner
5	Exhaust system connection
6	Outlet of compressed intake air to intercooler
7	Compressor bypass valve
8	Wastegate
9	Turbine control valve

High Pressure Stage

The high pressure stage is the smaller of the two exhaust turbochargers. This is designed as a so-called "integral manifold" as the housing for the exhaust turbocharger and the exhaust manifold are one single cast unit. The high pressure stage is not connected by a valve. The oil inlet and outlet provides the necessary lubrication of the bearing.

Low Pressure Stage

The large exhaust turbocharger houses the turbine control valve and wastegate. It is mounted on the exhaust manifold and is additionally supported against the crankcase. The low pressure stage also has a separate oil supply for the bearing.

Turbine Control Valve

The turbine control valve opens a bypass channel on the exhaust side to the low pressure stage (past the high pressure stage).
It is operated pneumatically by a vacuum unit and can be variably adjusted. An Electro-pneumatic pressure converter (EPDW) applies vacuum to the vacuum unit. In development, the turbine control valve is referred to as the main control valve.

Compressor Bypass Valve

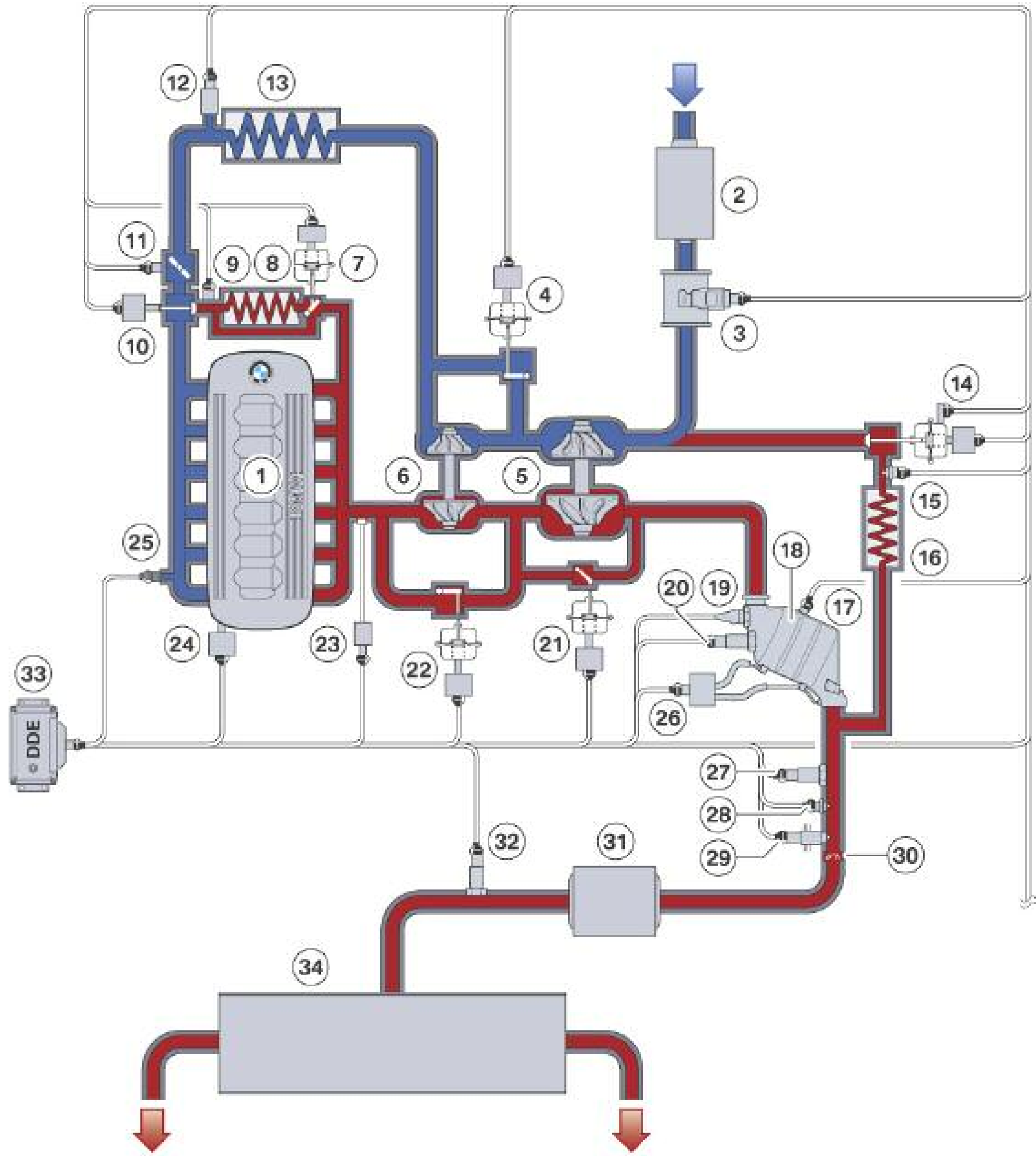
The compressor bypass valve controls the bypass of the high pressure stage on the air intake side. It is operated pneumatically by a vacuum unit. The compressor bypass valve is either fully opened or completely closed. An electric changeover valve (EUV) applies vacuum to the vacuum unit.

Wastegate

On reaching the nominal engine output, the wastegate opens to avoid high boost and turbine pressures. A part of the exhaust gas flows via the tailgate past the turbine of the low pressure stage. It is operated pneumatically by a vacuum unit. The wastegate can be variable adjusted.

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

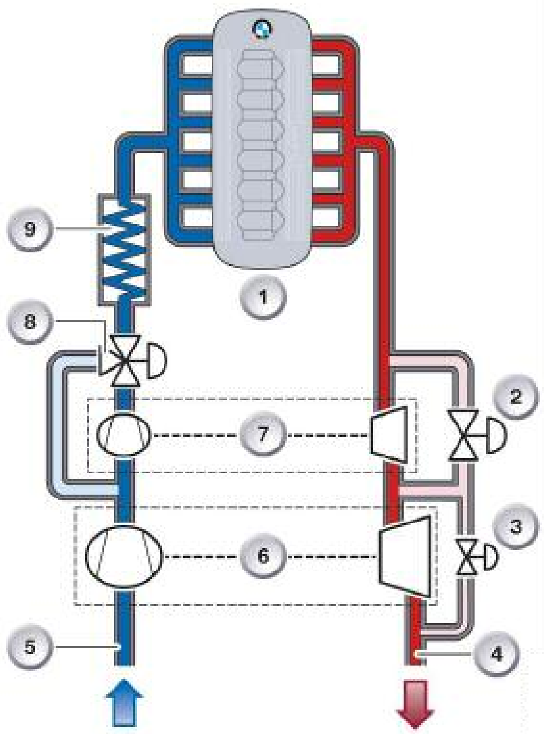
- Electric swirl flaps
- Electric exhaust gas recirculation valve (High pressure EGR valve)
- Low pressure EGR (E70 only)
- Turbo assembly adapted for low pressure EGR. (E70 only)



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)

Lower Engine Speed Range (up to 1500 rpm)

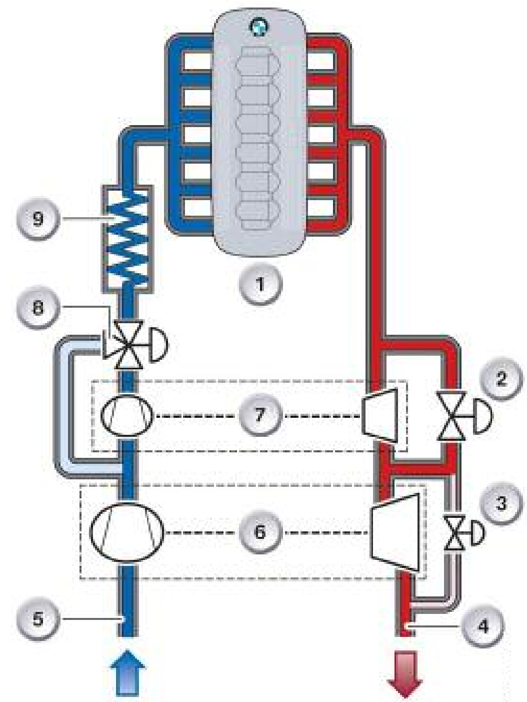
The turbine wheels of the high pressure and low pressure stages (6+7) are driven by exhaust gas. The engine is supercharged primarily by the high pressure stage (7).



Medium Engine Speed Range (from 1500 to 3250 rpm)

The turbine control valve (2) opens continuously as the engine speed increases. Consequently, the flow of exhaust gas increasingly bypasses the turbine wheel of the high pressure stage (7).

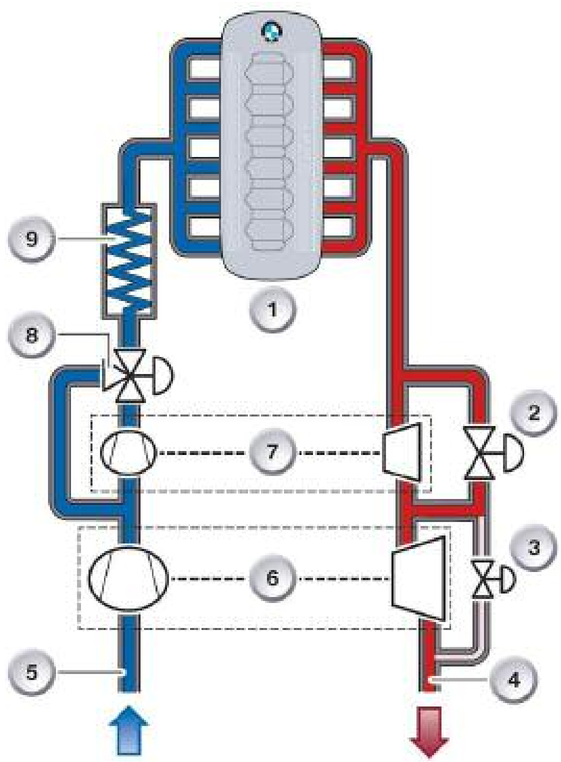
As the engine speed increases, the engine is supercharged more and more by the low pressure stage (6).

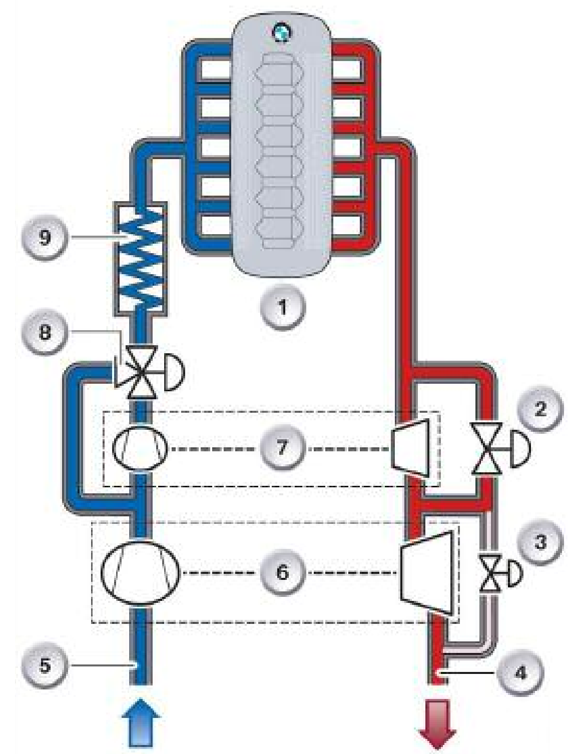


Index	Explanation	Index	Explanation
1	M57D30T2 Engine	6	Exhaust turbocharger - low pressure stage
2	Turbine control valve with electro-pneumatic pressure converter (EPDW)	7	Exhaust turbocharger - high pressure stage
3	Wastegate with electro-pneumatic pressure converter (EPDW)	8	Compressor bypass with electric changeover valve (EUV)
4	Exhaust gas to exhaust system	9	Intercooler
5	Fresh air from air cleaner		

Upper Engine Speed Range (from 3250 to 4200 rpm)
The turbine control valve (2) is completely open. The flow of exhaust gas largely bypasses the turbine wheel of the high pressure stage (7). The compressor bypass valve (8) is open. The engine is supercharged only by the low pressure stage (6).

Nominal Engine Speed Range (as from 4200 rpm)
The engine is supercharged by the low pressure stage (6). The wastegate (3) opens as the engine speed increases. A part of the exhaust gas therefore bypasses the turbine wheel of the low pressure stage, thus limiting the turbine speed.





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5	Fresh air from air cleaner		

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.

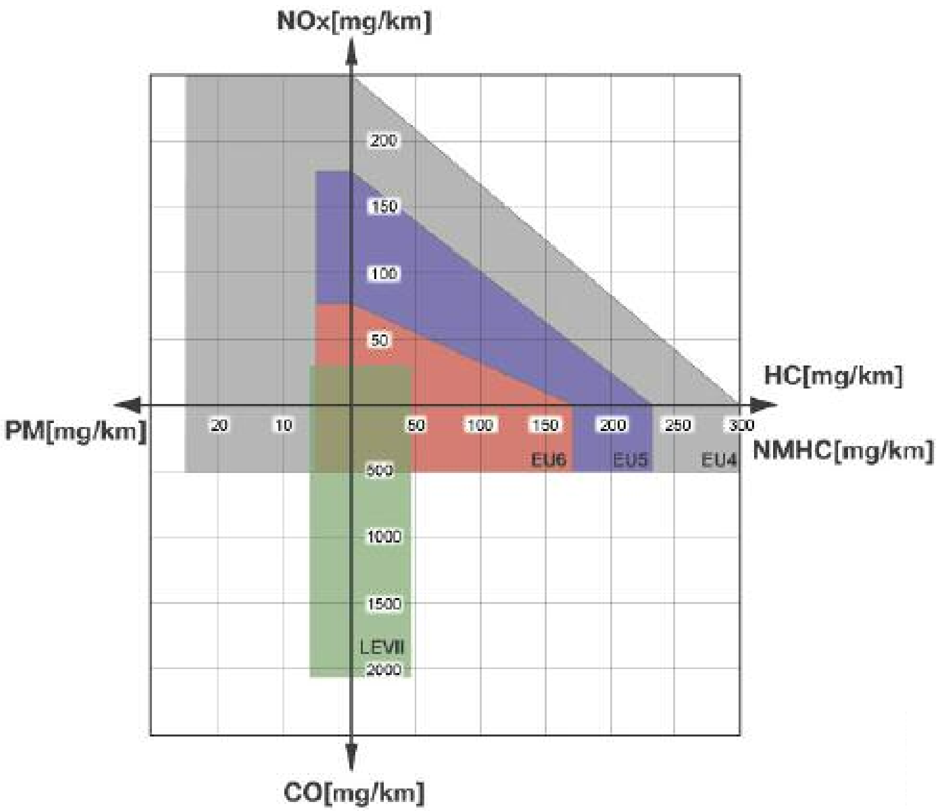
This legislation has lead to the development of different requirements with regard to the limitation of various components in the exhaust gas. Essentially, the following exhaust gas constituents are evaluated:

- 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.

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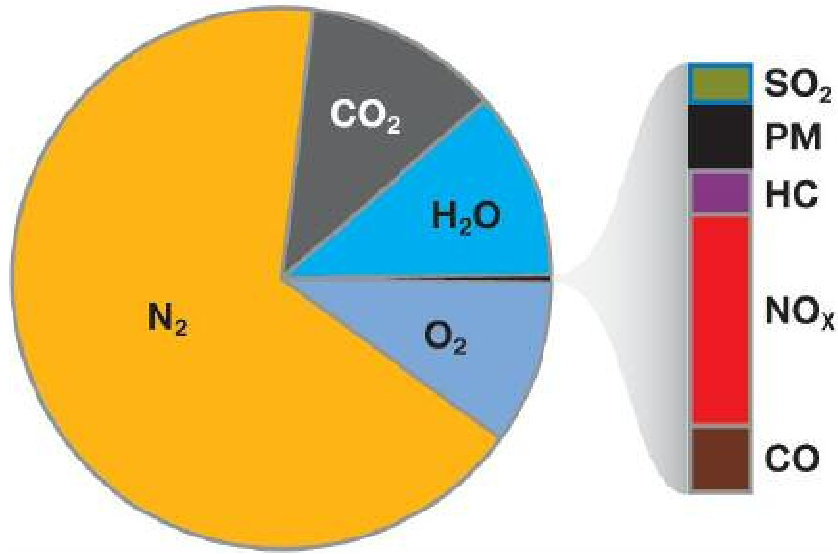
In a diesel engine, power output is dependent upon the amount of diesel fuel injected. The engine is operated in a very lean mode with excess air. The available excess air provides enough oxygen for more complete combustion. This lean operation reduces the overall Hydrocarbon (HC) and Carbon Monoxide (CO) emissions as compared to a gasoline engine. However, due the higher combustion chamber temperatures, Oxides of Nitrogen (NO_X) are a major concern.

Other concerns in a diesel engine include soot which is also known as Particulate Matter (PM). PM can be controlled in the engine or via exhaust after-treatment.

Diesel engine emissions can be controlled in one of 2 ways. One method is via what is known as "in engine" measures which are accomplished by changes in engine design or by the diesel engine management systems. The engine management system can control emissions via the fuel injection strategy.

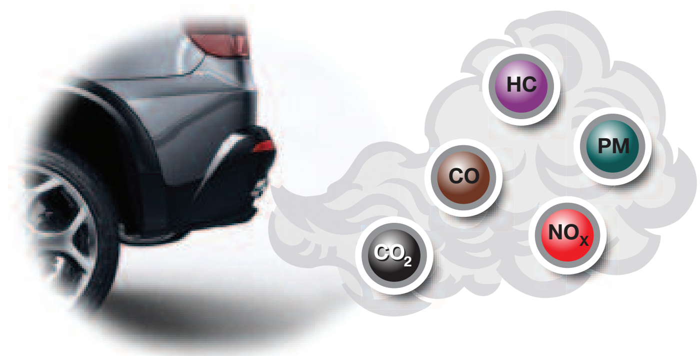
Emissions which cannot be controlled via the engine or engine management are the responsibility of the "after-treatment" system. Some of the methods employed as after-treatment systems are diesel oxidation catalysts, particulate filters and the new Selective Catalytic Reduction (SCR) systems.



Exhaust Gas Constituents before Exhaust Treatment

Combustion By-products

Exhaust gases are the by-product of a chemical reaction which occurs during the combustion process. Since diesel fuel is a hydrocarbon, the composition of the exhaust gas is similar to the exhaust gasses from a gasoline engine. However, these gasses are present in different percentages due to the lean operation of the diesel engine.



Hydrocarbons (HC)

Diesel fuel is a hydrocarbon, therefore any hydrocarbons that are present in the exhaust stream are considered unburned (or un-combusted). HC is a generic term for any chemical compound which unites Hydrogen (H) with Carbon (C). During combustion, new HC compounds are produced which are not initially present in the original fuel.

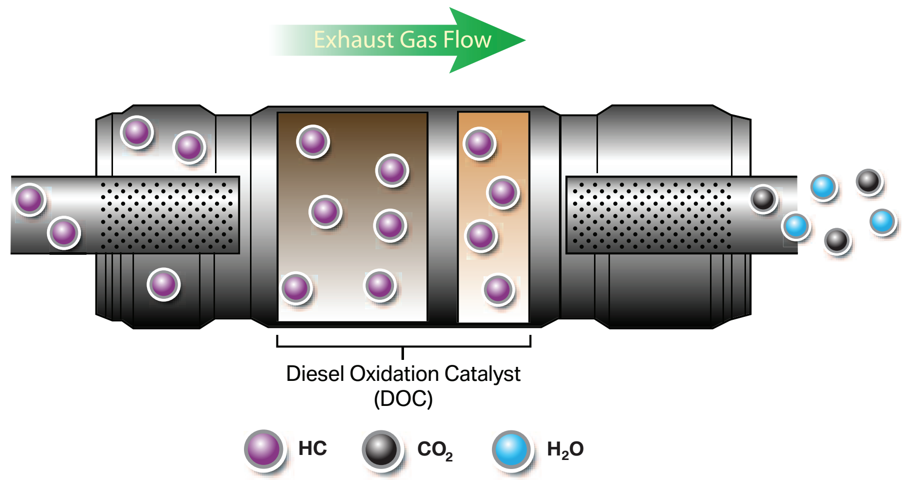
The HC is produced when there is insufficient oxygen to support complete combustion or if there are cylinder misfires. HC emissions are also produced in the "cooler" parts of the combustion chamber such as the area around the piston rings. These "cool" areas tend to quench the flame front, resulting in "un-combusted" hydrocarbons. A cold engine also tends to allow fuel to condense on the cylinder wall which has the same "quenching" effect.

Diesel engines do not produce a high level of HC, and most of the remaining HC after combustion is oxidized by the diesel oxidation catalyst (DOC).

Effects of HC Emissions

Hydrocarbon emissions are a component of ground level ozone which has become an issue in many cities across the US. As one of the primary building blocks of smog, ground level ozone is created by chemical reactions between HC and nitrogen oxides in the presence of sunlight.

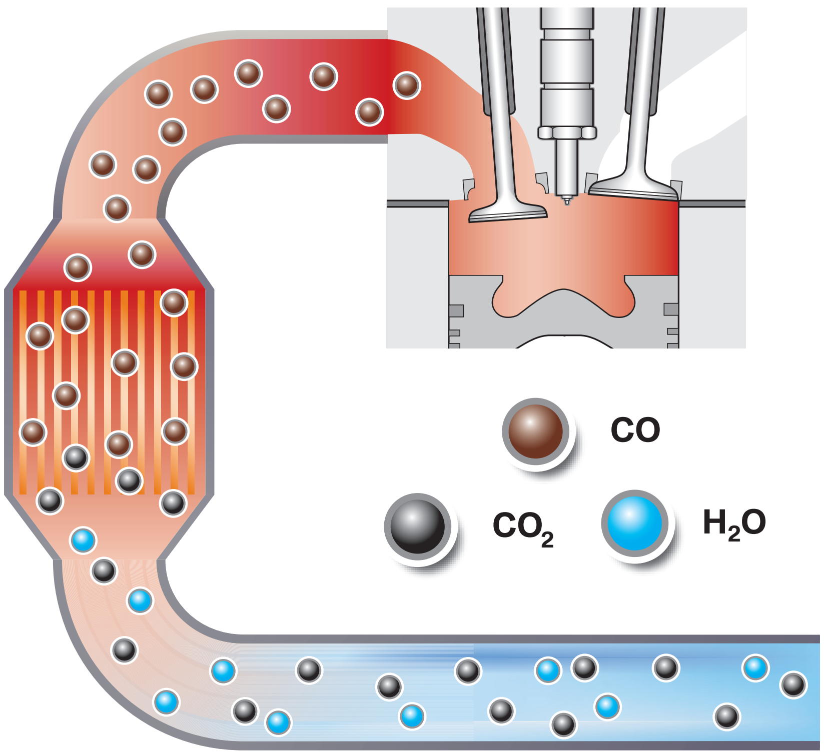
Ozone at ground level contributes to numerous health problems including lung damage and cardiovascular functions. Also, hydrocarbons are also considered toxic.



Carbon Monoxide

Carbon Monoxide (CO) is formed when there is insufficient oxygen to support combustion. This condition results in partially burned fuel. During normal combustion, Carbon atoms combine with oxygen atoms to produce Carbon Dioxide (CO_2) and water vapor. When there is a lack of oxygen (or excess fuel) during combustion, Carbon Monoxide is formed.

Carbon Monoxide is not usually a concern in modern "lean burn" diesel engines. Output of CO is minimal in a diesel engine and most of the residual CO is processed (oxidized) by the diesel oxidation catalyst.



Effects of CO Emissions

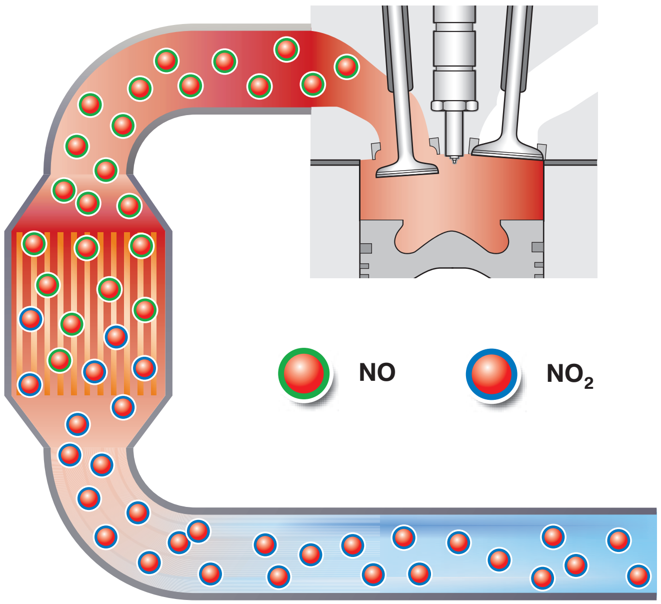
Carbon Monoxide is a colorless, odorless and tasteless gas which is poisonous to humans and other air breathing creatures. When inhaled, CO takes the place of oxygen in red blood cells. Red blood cells normally transport oxygen to all of the bodies tissues. When oxygen is substituted by CO in the bloodstream, a condition known as hypoxia occurs. This ultimately causes asphyxiation which can result in severe illness or death. Even in small amounts, CO can cause illness and headaches.

In the environment, CO contributes to the "greenhouse" effect. Although CO is considered a primary pollutant today, it has always been present as a result of brush fires and volcanic activity.

Oxides of Nitrogen (NO_X)

NO_X is an all-inclusive term for chemical compounds consisting of nitrogen (N) and oxygen (O). NO_X consists of mostly NO (Nitric Oxide) and NO_2 (Nitrogen Dioxide).

Since the ambient air contains both Nitrogen and Oxygen, NO_X is formed when these two elements combine in the heat of combustion. Nitrogen and Oxygen do not combine until the combustion chamber temperature exceeds 1100°C.



One of the major factors in the formation of NO_X is the overall combustion chamber temperature. Diesel engines have inherent issues regarding the production of NO_X.

Due to the fact that diesel engines have a very high compression ratio, the combustion chamber temperatures are, of course, high as well. This in turn, initiates the optimal conditions for NO_X formation. Also, the lean mixtures in a diesel engine contribute to additional available oxygen in the combustion chamber. This, in turn, is a factor in the higher combustion chamber temperatures.

More than 50% of NO_X emissions are derived from mobile sources i.e cars, trucks and buses etc.. This includes “on-road” as well as “off-road” sources.

NO_X reduction can be addressed by engine management or by exhaust “after-treatment”.

Effects of NO_X Emissions

NO_X emissions , along with HC and sunlight, contribute to the formation of photochemical smog. Smog is attributable to numerous health issues and is classified by the E.P.A. as major contributor to health issues including respiratory and heart related illnesses.

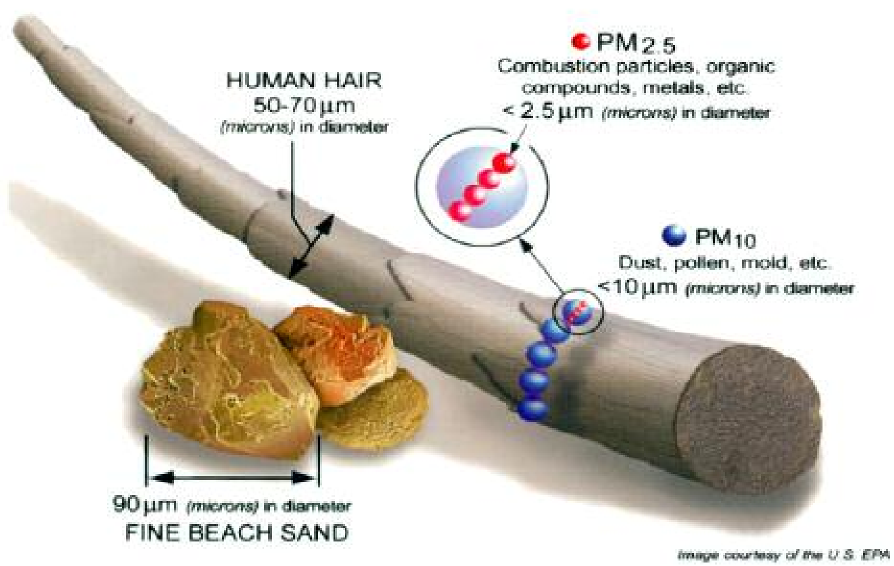
NO_X is also responsible for the formation of ground level ozone, which is also a major irritant of the respiratory system. Ozone is of particular concern to those suffering from asthma.

In the environment, both ozone and NO_X are considered to of the major greenhouse gasses which contribute to global warming.

Particulate Matter

One area where diesels are less than desirable is in the area of particulate matter emissions or "PM". PM emissions are more commonly referred to as soot. Although diesel engines emit less HC and CO, soot is derived from any unburned fuel. Sulfur is one of the origins of soot in diesel exhaust. The reduction of sulfur content in the fuel is one way to reduce overall PM emissions.

Particulate matter emissions are classified in two groups which are based on particle size. PM10 refers to those particulates which are less than or equal to 10 microns and PM2.5 has a particle size of 2.5 microns or less.



Diesel exhaust consists of mostly the smaller (PM2.5) particles. Particulate matter is considered a harmful pollutant which contributes to respiratory problems. Therefore, PM emission should be controlled.

PM emissions can be reduced in a number of ways. One of the first and most practical measures is to reduce the sulfur content in the fuel. As of 2007, the new ULSD fuel has a limit of 15 ppm sulfur. This represents a major reduction over the former 500 ppm limit.

Engine design and engine management systems can greatly contribute to a reduction in PM emissions by ensuring the most efficient engine operation. Perhaps the most effective method of reducing PM emissions is found in the exhaust after-treatment systems.

The diesel oxidation catalyst (DOC) has proven to be somewhat effective in breaking down the constituents of PM. However, the DOC is not enough to meet the current emission standards regarding particulate matter emissions. This is where the diesel particulate filter (DPF) becomes an important element of overall PM reduction.

Sulphur Dioxide

Sulphur dioxide, (SO_2), enters the atmosphere as a result of both natural phenomena and anthropogenic activities, e.g.:

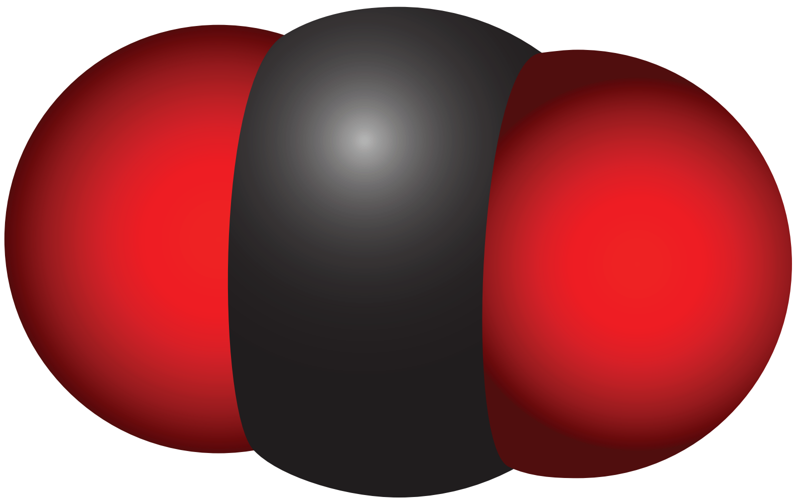
- combustion of fossil fuels
- oxidation of organic material in soils
- volcanic eruptions
- biomass burning.

Coal burning is the single largest man-made source of sulphur dioxide, accounting for about 50% of annual global emissions, with oil burning accounting for a further 25 to 30%. Sulphur dioxide reacts on the surface of a variety of airborne solid particles (aerosols), is soluble in water and can be oxidized within airborne water droplets, producing sulphuric acid. This acidic pollution can be transported by wind over many hundreds of kilometers, and is deposited as acid rain.

Carbon Dioxide

Carbon dioxide (CO_2) is one of the constituents in the exhaust of any internal combustion engine. When an engine is running in its most efficient state, the major portion of the exhaust gas consists of carbon dioxide and water. As a matter of fact, it can be said that the efficiency of an engine can be measured by the CO_2 content in the exhaust.

Carbon Dioxide Molecule



Ironically, CO_2 is one of the major contributors to the theory of global warming. Although CO_2 is a natural, non-toxic component of the earth's atmosphere it is now present in a disproportionate amount. Scientists agree that this situation is now contributing to the warming of our global environment. It is also important to note that atmospheric CO_2 is not only the result of automobile emissions, but overall industrialization from sources such as manufacturing, power generation and transportation sectors.

Since CO_2 production in an internal combustion engine is a measure of an engine's overall efficiency, reducing CO_2 output is a challenge.

Since CO_2 output is directly proportional to the amount of fuel consumed, it would make sense to improve overall fuel economy. Currently, the best way to reduce CO_2 output is to improve the overall efficiency.

Some of these new measures on BMW diesel vehicles include:

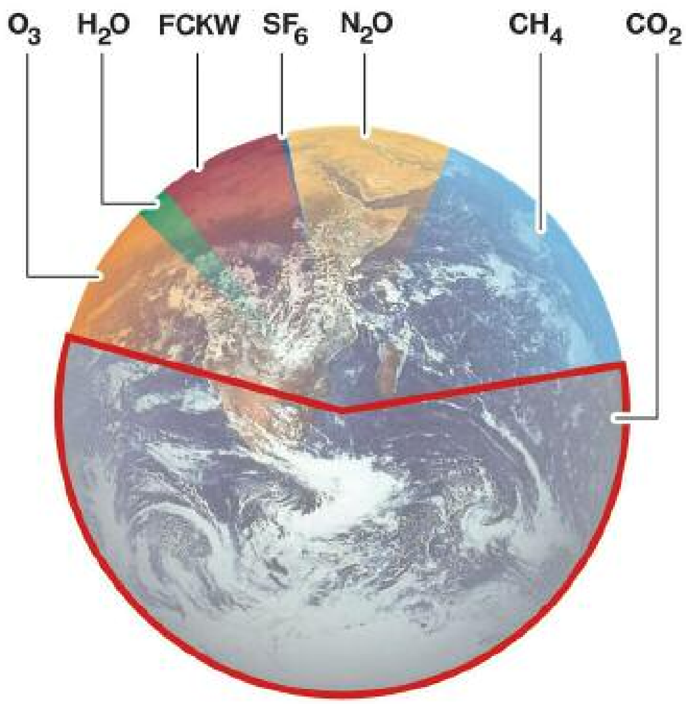
- The addition of Electric Power Steering (EPS) which reduces the parasitic load of hydraulic (belt driven) power steering
- The addition of an A/C compressor clutch (previous models omitted clutch)
- Lightweight vehicle and engine construction
- Tires with reduced rolling resistance (future)

The items mentioned above are just a few of the measures to reduce CO_2 emissions. As part of BMW's "Efficient Dynamics" concept, many new advances in "clean" diesel technology are on the horizon.

When reducing CO_2 output by way of engine measures, the resulting leaner operation results in increased NO_X output. In the future these situations will be countered by Selective Catalytic Reduction (SCR).

Diesel Emission Control Systems

Taking all of the positive aspects of diesel engines into consideration, perhaps the most challenging aspect of diesel engine design is the reduction of emissions. Diesel engines are much more efficient than gasoline engines, but have some inherent emission concerns due to the fuel used and the lean running strategy.



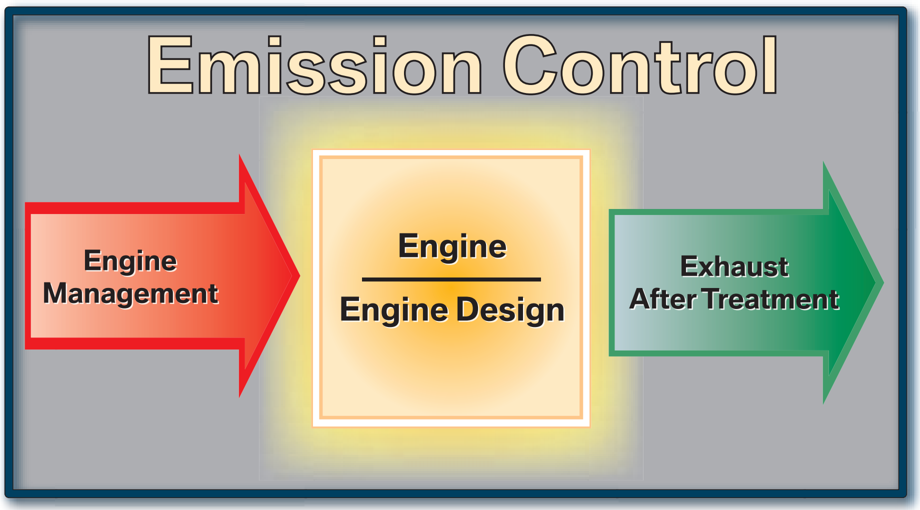
Diesel engines have a high combustion chamber temperature which contributes to excessive NO_X production. The high combustion chamber temperatures are due to the high energy content of diesel fuel and the lean mixture. The lean mixture does not have the same cooling effect of the "richer" mixture found in gasoline engines.

Gasoline engines run at the "stoichiometric" ratio of 14.7 to 1 otherwise known as lambda = 1. Diesel engines have a variable air/fuel ratio which varies between a lambda value of 1.15 to 2.0. Under idle and no load conditions this could increase to a lambda value of 10.

Particulate emissions are also a concern in diesel engines due to the sulfur content in the fuel used. Even though most new diesel vehicles will run on ULSD diesel, the PM emissions are still high enough to be a concern. So, measures must be taken to reduce the overall soot content in the exhaust.

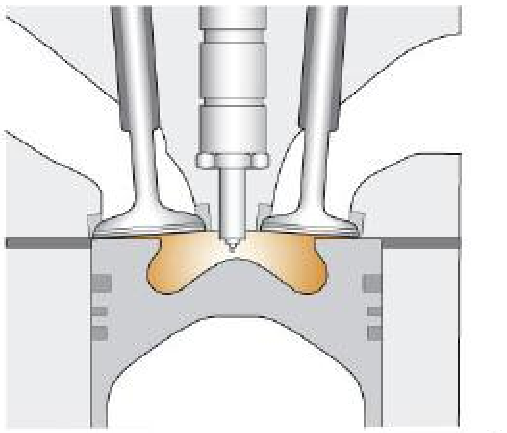
On diesel engines, the reduction of emissions can be classified into two major categories.
The two categories include:

- "In-engine" measures
- Exhaust after-treatment



Engine Measures to Reduce Emissions

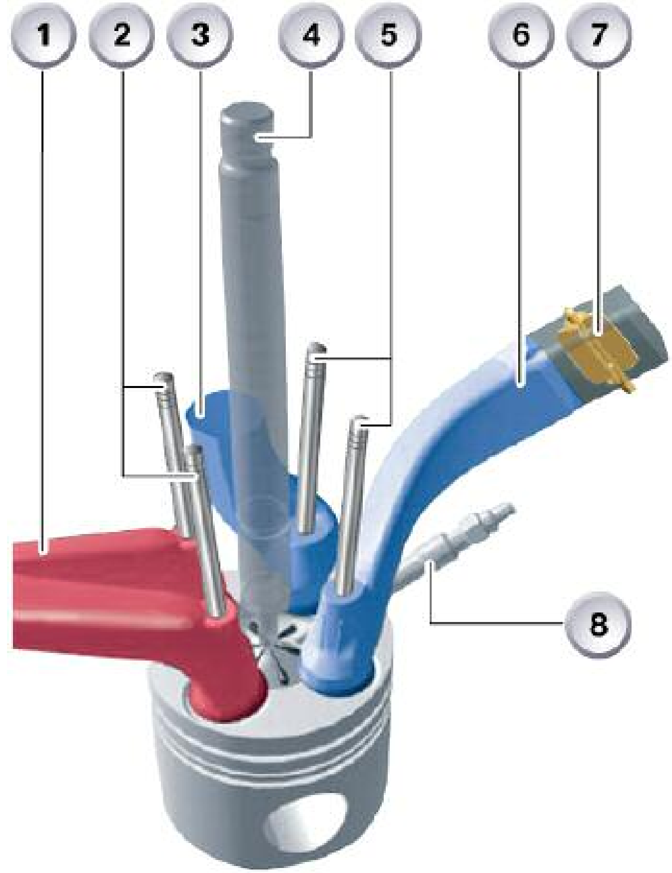
The “in-engine” measures include design elements in the mechanical structure of the engine as well as engine management intervention. In order to reduce unwanted levels of emissions, the engine design should contribute to the best possible level of efficiency.



For example, the shape of the combustion chamber has an effect on fuel mixing. The mixture can be influenced or “shaped’ by the piston design and the angle at which the fuel is injected. The intake manifold and intake ports can be designed to provide more air motion in the combustion chamber. This is referred to as the “swirl effect”. By providing this air movement via “swirl”, the air is better mixed with the atomized fuel and thus contributes to lowered emissions.

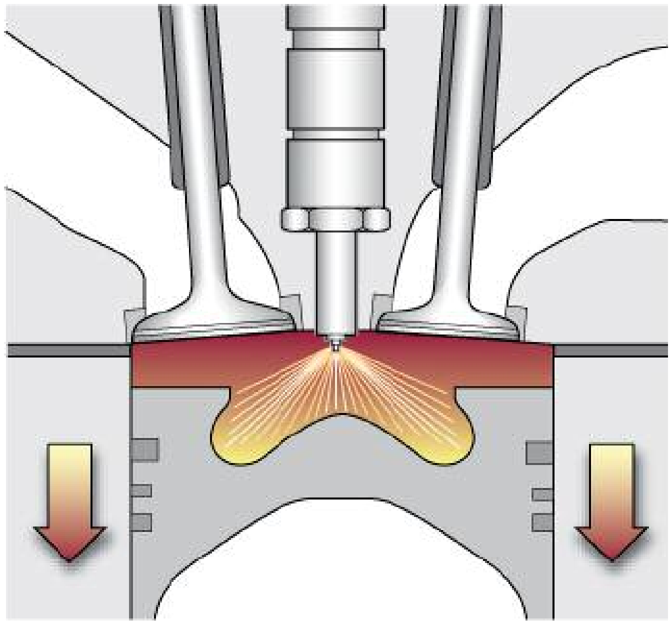
At low RPM the swirl in the combustion chamber lowers NO_X values in the lower RPM range. BMW engines take advantage of this by using an intake manifold with swirl flaps which can by controlled via the diesel engine management (DDE).

If the swirl flaps stick open, low RPM emissions will be affected. If the swirl flaps stick closed, high RPM power will be noticeably reduced.



Index	Explanation	Index	Explanation
1	Exhaust ports	5	Intake valves
2	Exhaust valves	6	Intake (tangential) port
3	Swirl Port	7	Swirl flap
4	Fuel injector	8	Glow plug

Injection Strategy
Besides mechanical methods, the engine management system can influence overall emission output. This strategy is carried out via the fuel injection system. Modern diesel fuel injection systems are very precise and use extremely high pressures to improve overall efficiency and emission levels.



The injection system on a diesel engine functions, in some ways, much like an ignition system on a gasoline engine. In order to start combustion, it is necessary to inject fuel at the right time with reference to the position of the piston. Just like an ignition system on a gasoline engine, the injector must inject fuel before top dead center (BTDC).

The injection strategy can also be modified to inject fuel at different times (i.e. ATDC) and can have multiple injection events. Fuel can be injected ATDC to help the catalyst achieve operating temperature earlier. The injection strategy can also be modified to assist in heating the DPF (DPF is discuss in the “Exhaust after-treatment” section of this workbook).

For example, the start of injection can be between 2 and 4 degrees BTDC when there is no load present (such as during idle). Under full load conditions, the start of injection can be moved to 15 degrees BTDC.

However, starting the injection event too early can be counter productive. The early start of combustion can actually resist the movement of the piston and cause a loss of power and an increase in emissions.

Multiple Injection
The introduction of the third generation common rail facilitates finer distribution of the fuel injection per power stroke. Instead of injecting the fuel in two stages per power stroke (pre-injection for minimizing noise and main injection for developing power) as was previously the case, the fuel is now injected in up to 3 stages.

As a result, the engines run even more quietly and produce less nitrogen oxides and soot particles.

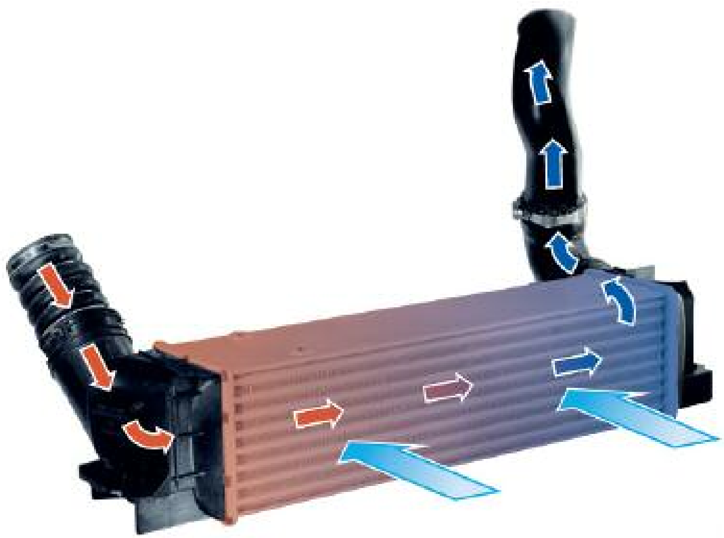
The following factors enable triple injection:

- Increased processing capacity of the DDE
- Higher efficiency of the coils in the fuel injectors

Operating Range	M57 TU Injection Strategy
Near Idle Speed	2 pre-injections 1 main-injection
Partial Load	1 pre-injection 1 main-injection 1 post-injection
Full Load	1 pre-injections 1 main-injection
Maximum Output	1 main-injection

Charge Air Cooling
More commonly known as intercooling, BMW turbo-diesel engines benefit from charge air cooling in several ways. Besides increasing charge air density, the intercooler also reduces NO_X as an added benefit of the reduced charge air temperature.

Usually, the intercooler is not associated as being an emission control device. But, due to the high combustion chamber temperature in a diesel engine the intercooler is now providing an important function with regard to NO_X reduction.



Exhaust Gas Recirculation (EGR)
BMW gasoline engines currently, do not use a more conventional "external" EGR system. EGR on BMW gasoline engines is considered an "internal" system which is carried out via the variable camshaft control system (VANOS).

The VANOS system modifies the camshaft timing to achieve a precise amount of valve overlap. The valve overlap allows a certain amount of EGR to occur, thus lowering NO_X significantly.

Mostly, gasoline engines respond to an EGR flow rate of about 5 to 15%. BMW gasoline engines are able to benefit from the "internal" method of EGR due to engine design and the engine management strategies.

In the case of diesel engines, which run in a constantly lean mode, the NO_X content in the exhaust gas is much higher. Therefore, the "internal EGR" method is not able to sufficiently lower NO_X to acceptable levels. So, BMW diesel engines employ an external EGR system to meet these needs. Diesel engines benefit from EGR rates as high as 50% under certain operating conditions.

Unlike gasoline engines, diesels can introduce EGR at idle. This is due to the fact that the diesel has a mostly open throttle at idle. This helps reduce NO_X at idle which is when a diesel is most lean.

The recirculated exhaust gas, which is mixed with the fresh air and acts as an inert gas, serves to achieve the following:

- A lower oxygen and nitrogen concentration in the cylinder,
- A reduction in the maximum combustion temperature of up to 500°C. This effect is increased still further if the recirculated exhaust gases are cooled.

The EGR valve is located in the throttle housing. Exhaust gas is ducted from the exhaust manifold to the throttle housing. There is a connection at the forward end of the manifold for this purpose. Connected here is the EGR valve, which controls the volume of recirculated exhaust gas.

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:

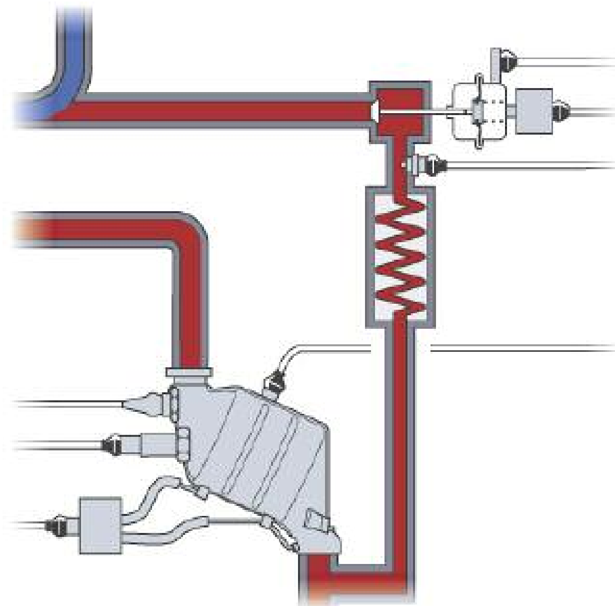
- Lower exhaust gas temperature - The exhaust gas for the low pressure EGR is tapped off at a point where a lower temperature prevails than in the high pressure EGR. Consequently, the exhaust gas has a higher density thus enabling a higher mass.

  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.

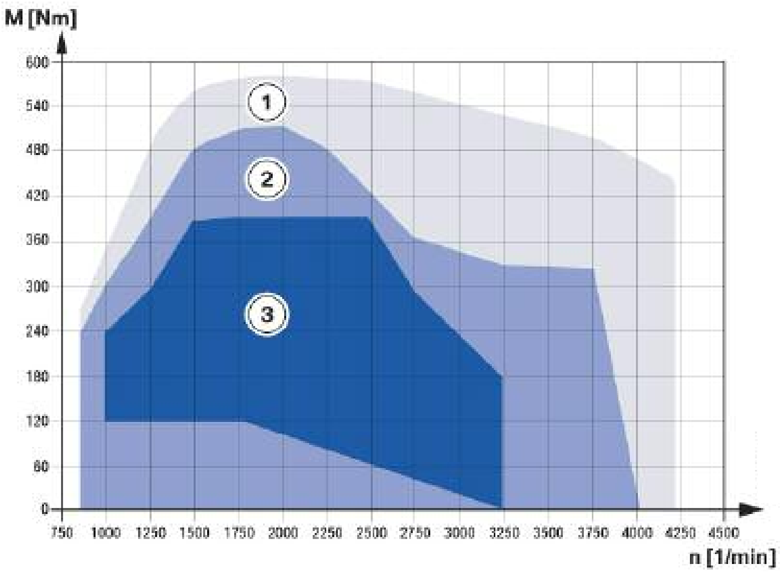
- Recirculation before the exhaust turbocharger - Unlike in the high pressure EGR where the exhaust gas is fed to the charge air already compressed, in this system the exhaust gas is added to the intake air before the exhaust turbocharger.
  A lower pressure prevails in this area under all operating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



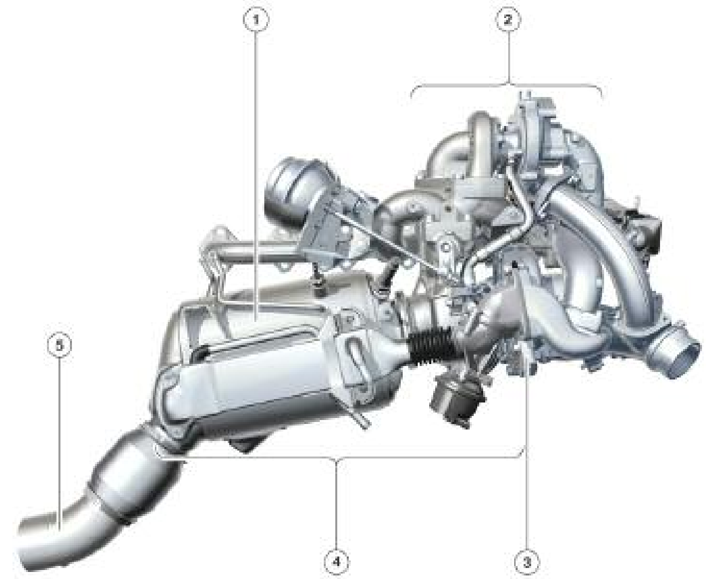
Index	Explanation	Index	Explanation
1	No EGR	3	High and low pressure EGR are active
2	Only high pressure EGR is active		

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.

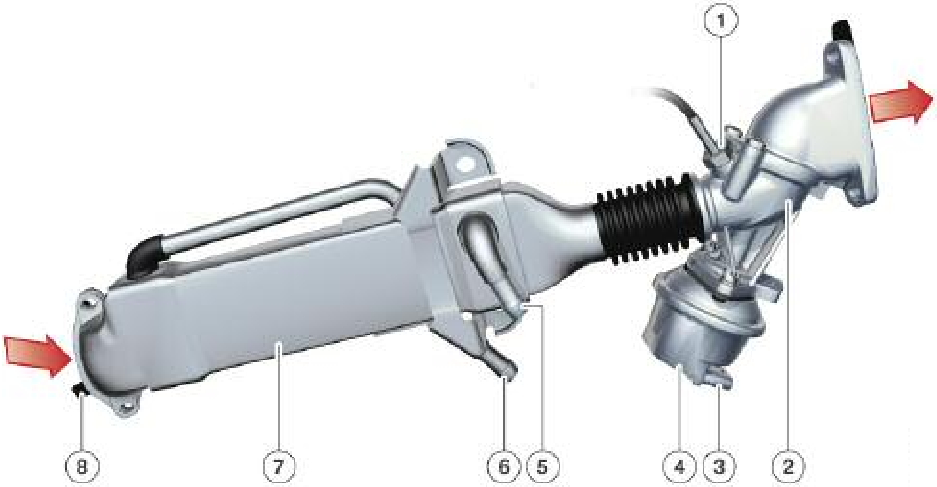
Added to this, it is only activated at a coolant temperature of more than 55°C. The low pressure EGR valve is closed as from a certain load level so that only the high pressure EGR valve is active again. This means the EGR rate is continuously reduced.

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:

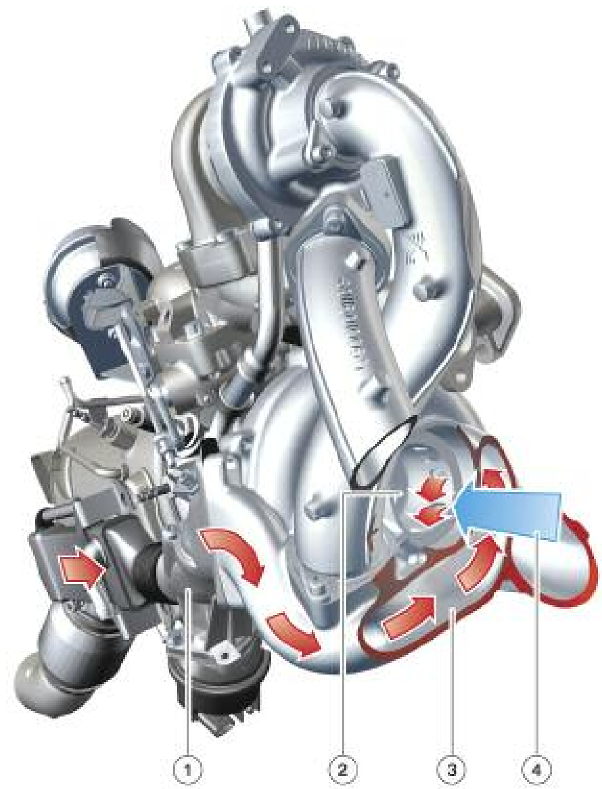


Index	Explanation	Index	Explanation
1	Temperature sensor - LP EGR	5	Coolant infeed
2	LP-EGR valve	6	Coolant return
3	Connection for positional feedback	7	LP-EGR cooler
4	Vacuum unit for LP-EGR valve	8	Sheet metal gasket with filter

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.

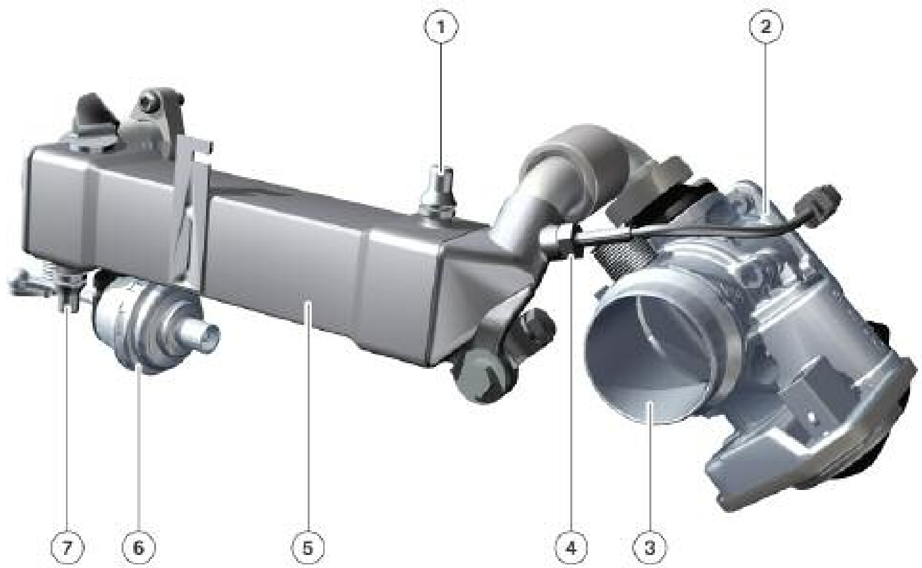
On the one hand, the inlet for the low pressure EGR is located on the compressor housing for the low pressure stage. On the other hand, the compressor wheels are nickel-coated to protect them from the exhaust gas.

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:

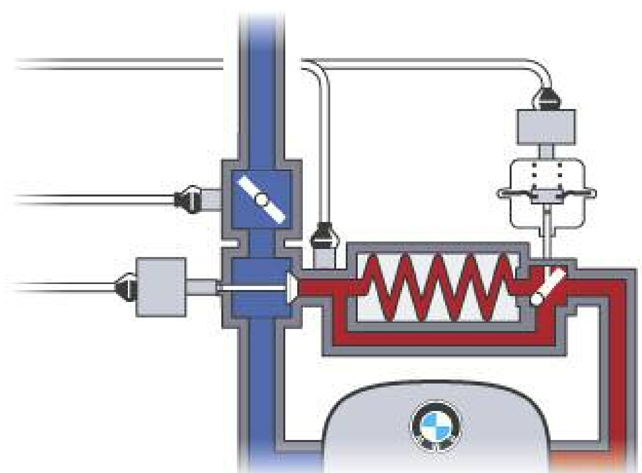
- Travel of high pressure EGR valve
- Temperature before high pressure EGR valve
- Pressure difference between exhaust gas pressure in the exhaust manifold and boost pressure in the intake manifold.

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.

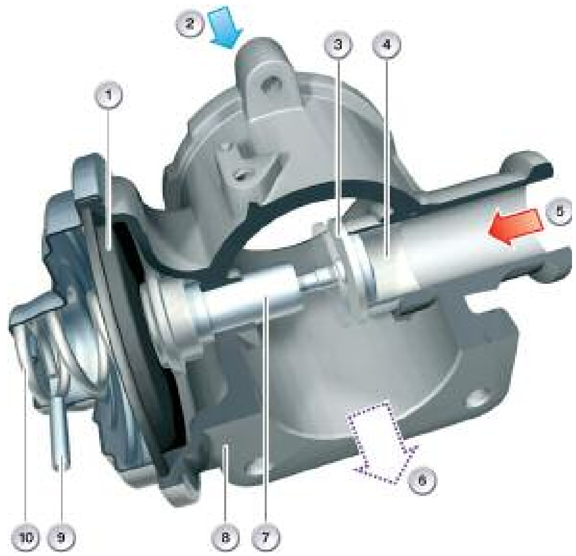
In this case, the EGR cooler can be bypassed in order to heat up the combustion chamber faster. For this purpose, there is a bypass that diverts the flow of the exhaust around the EGR cooler.

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.



EGR Control

The EGR valve opens by applying vacuum at vacuum connection (9). The vacuum presses diaphragm (1) against spring (10) and the EGR valve head is lifted from blade-type sleeve (4). Exhaust gas (5) can now flow past the EGR valve head into the intake port.



Index	Explanation
1	Diaphragm
2	Intake air from throttle valve
3	EGR Valve head
4	Blade type sleeve
5	Incoming exhaust gas
6	Fresh air/Exhaust gas mixture
7	Guide sleeve
8	EGR housing
9	Vacuum connection
10	Spring

The exhaust gas now mixes with the intake air from throttle valve (2) and is directed in the form of a fresh air-exhaust gas-air mixture (6) to the engine. The blade-type sleeve has the advantage that, when the EGR valve is closed, any deposits formed on the sleeve are removed by the blade shape, ensuring the EGR valve always closes reliably. In this way, a coking ring is prevented from forming on the surface of the valve seat.

EGR Cooling

The use of an EGR cooler increases the efficiency of exhaust gas recirculation. The cooled exhaust gas is able to draw off more thermal energy from the combustion and thus reduce the maximum combustion temperature. Actually, the “cooled” exhaust gas will allow a greater volume of exhaust gas to be recirculated.

The EGR cooler is located in the forward end face of the cylinder head. It is supplied with coolant from the cooling system in the crankcase directly downstream of the coolant pump. The coolant flows through the EGR cooler and, in the process, around the pipes carrying the recirculated exhaust gas. Heat is transferred to the coolant. After passing through the EGR cooler, the coolant flows into the cylinder head.

Exhaust After-treatment

Diesel Oxidation Catalyst (DOC)

The DOC is responsible for specific functions in the after-treatment of diesel exhaust. It is mounted as close to the engine as possible for maximum effectiveness over the entire operating range of the engine.

The functions are as follows:

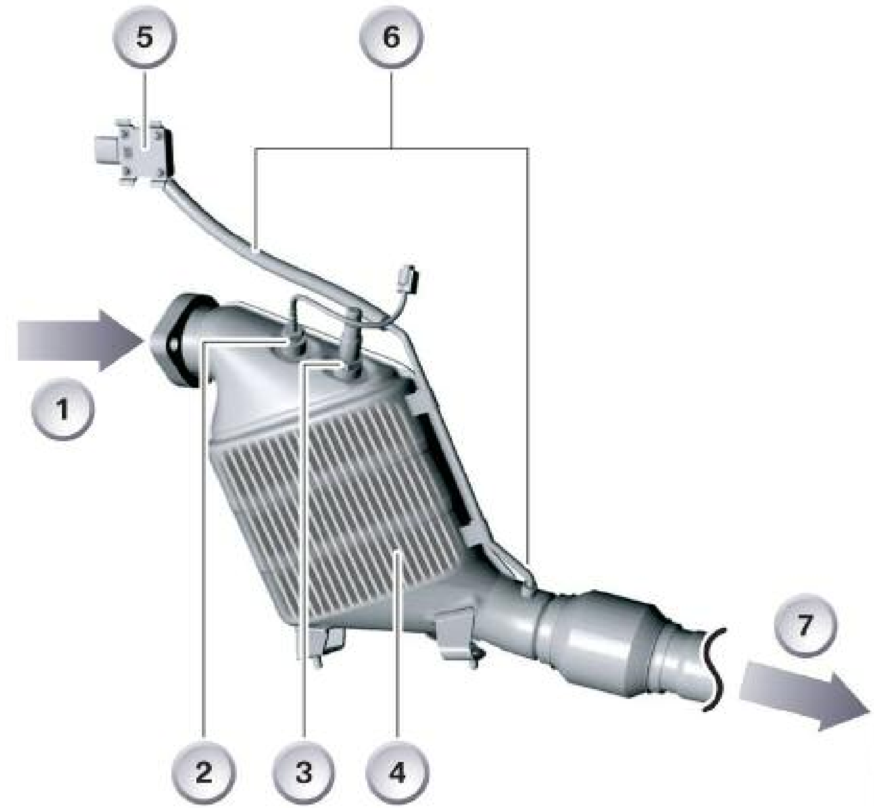
- Reduction in HC emissions
- Reduction in CO emissions
- Oxidation of NO into NO_2
- Reduction of particle mass
- To increase exhaust temperature for the regeneration phase of the DPF

In most systems, Diesel Oxidation Catalysts (DOC's) consist of a stainless steel canister that contains a honeycomb structure called a substrate or catalyst support. It contains no moving parts, only an interior surface coated with catalytic metals such as platinum or palladium.

The DOC is mounted as close to the engine as possible to take advantage of available exhaust heat.

The exhaust in a diesel engine does not contain high amounts of HC and CO, but these gasses must be converted into more harmless gasses.

Note: Newer diesel vehicles incorporate the DOC and the DPF in the same housing.

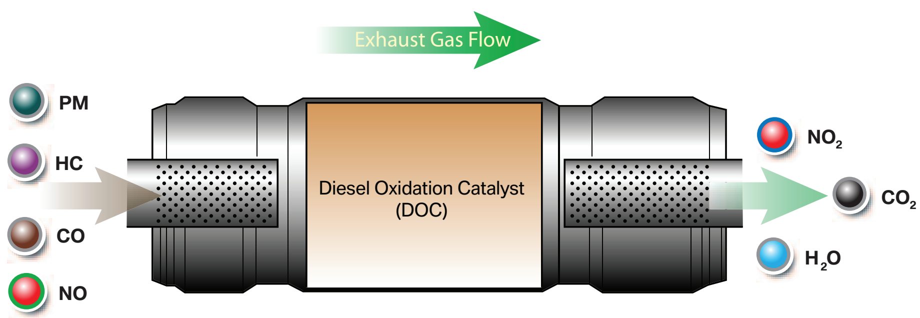


Index	Explanation	Index	Explanation
1	Exhaust gasses (pre-cat)	5	Exhaust pressure sensor
2	Exhaust gas temperature sensor	6	Pressure tube
3	Oxygen sensor	7	Exhaust gas
4	DOC housing		

Reduction of Unwanted Emissions

The near-engine oxidation catalytic converter ensures the conversion of the following exhaust gas constituents across the entire operating range:

- Carbon monoxide (CO) is converted into carbon dioxide (CO_2)
- Hydrocarbons (HC) are converted into water (H_2O) and carbon dioxide (CO_2)
- Nitrogen monoxide (NO) is converted into nitrogen dioxide (NO_2)
- Soot particles are also reduced in the DOC by about 15 to 30%



Soot particles flow through the oxidation catalytic converter unimpeded. The oxidation catalytic converter is additionally used to increase the temperature during regeneration of the diesel particulate filter. The ceramic carrier (cordierite) features a platinum-based oxidation coating.

The resulting NO_2 from the conversion process is also used downstream in the particulate filter (DPF) and in the SCR system.

Due to the high oxygen content of the exhaust gas, the oxidation catalytic converter starts to work at approximately 170°C. Above around 350°C, the particle emissions begin to increase again.

Sulphates form due to the sulphur content of the fuel (sulphur-oxygen compounds). The use of ULSD fuel contributes to a reduction in overall particle formation.

Diesel Particulate Filter

In order to combat PM emissions, a diesel particulate filter was developed in order to store and then “burn off” accumulated soot. The filter element of the diesel particulate filter consists of a ceramic honeycomb made of heat-resistant silicon carbide. It is up to 50% porous and has a platinum-based, catalytic coating.

The DPF will trap and store soot in the channels in the honeycomb structure. At certain intervals, the DPF will go through a “regeneration phase” to burn off the residual soot.

The high temperature generated by the exhaust heats the ceramic structure and allows the particles inside to break down (oxidize) into less harmful components.

Function of the DPF

The diesel particulate filter ensures the conversion of the following exhaust gas constituents:

- $C + {}_2NO_2 \Rightarrow CO_2 + {}_2NO$
- $C + O_2 \Rightarrow CO_2$
- ${}_2CO + O_2 \Rightarrow {}_2CO_2$

The coating of the catalyst helps to achieve a reduction in the soot ignition temperature and thus to guarantee good regeneration characteristics of the diesel particulate filter.

The exhaust gases flow out of the oxidation catalytic converter and into the inlet ducts of the diesel particulate filter. These are closed at their ends. Each inlet duct is surrounded by four exhaust ducts.

The soot particles deposit on the platinum coating of the inlet ducts and remain there until they are combusted as a result of an increase in the exhaust temperature.

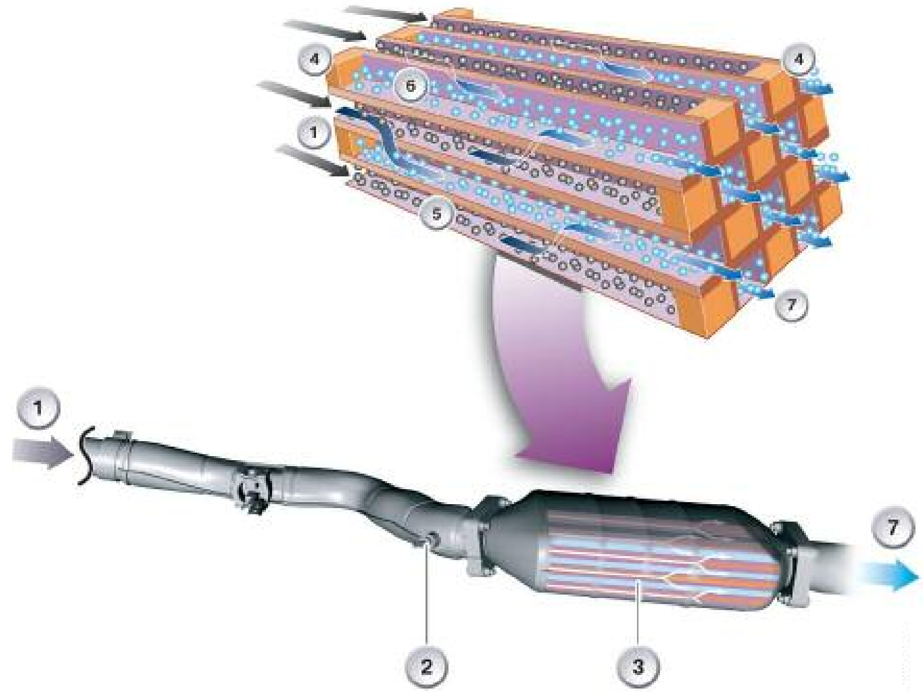
The cleaned exhaust gas flows out of the exhaust ducts through the platinum-coated, porous filter walls. Soot is only converted during vehicle operation under certain conditions such as full throttle situations. However, the optimum conditions are not always present is sufficient time intervals to remove soot, so a filter regeneration phase can be induced by the DDE periodically.

Filter Regeneration

The soot particles (carbon particles) that are deposited on the filter walls would eventually cause damage to the diesel particulate filter. The soot particles therefore need to be burnt off. This can happen when the exhaust temperature rises above the soot ignition temperature. This process occurs under certain vehicle operational situations or when the DDE initiates the process. This process is known as filter regeneration. The soot and carbon particles are converted to gaseous carbon dioxide (CO_2).

Soot particles have a relatively high ignition temperature. So, the exhaust temperature must be raised in order to initiate a regeneration phase. The exhaust temperature is raised by "post injection" events. The DDE system triggers the injectors after initial combustion has taken place. This raises the exhaust temperature, which in turn burns off the accumulated soot particles.

The DDE will initiate regeneration every 300 to 500 miles depending on several factors. Mostly, the regeneration is transparent to the driver. There may be a light loss of power for a short period while the soot is burned off.



Index	Explanation	Index	Explanation
1	Exhaust gas from DOC with soot particles	5	Inlet channel
2	Exhaust gas temperature sensor	6	Outlet channel
3	Diesel particulate filter (DPF)	7	Cleaned exhaust gas without soot particles
4	End of filter element		

Note: Newer diesel vehicles incorporate the DOC and the DPF in the same housing.

Sensors - Exhaust System

Exhaust Temperature Sensor

The DDE requires the exhaust temperature for controlling regeneration of the diesel particulate filter. The exhaust temperature sensor is designed as an NTC resistor sensor (the resistance decreases as temperature increases).

Version with Two Exhaust Temperature Sensors

One exhaust temperature sensor is located upstream of the oxidation catalytic converter and the other upstream of the diesel particulate filter.

Temperature	Resistance	Voltage
-40°C	Approx 96 k Ohms	Approx. 4.95 V
+/-40°C	Approx 30 k Ohms	Approx. 4.84 V
+ 100°C	Approx 2.79 k Ohms	Approx. 3.68 V
+ 800°C	Approx. 31.7 k Ohms	Approx. 0.15 V

An exhaust temperature in excess of 240°C is required for regenerating the filter. Initiating the filter generation procedure at temperatures below 240°C would produce white smoke caused by excess hydrocarbon (HC).

The exhaust temperature sensor upstream of the oxidation catalytic converter ensures the regeneration procedure is only enabled at temperatures above 240°C.

The exhaust temperature upstream of the diesel particulate filter is registered in order to control post-injection and therefore the exhaust temperature itself ahead of the diesel particulate filter.

Depending on the type of vehicle, the exhaust temperature sensor upstream of the diesel particulate filter sets a temperature between 580°C - 610°C based on the post-injection volume.

Three different types of sensors are used in the exhaust system. These sensors detect the exhaust temperature, exhaust backpressure and exhaust composition (oxygen sensor). The location and number of exhaust temperature sensors vary depending on the type of vehicle.

Exhaust System with One Exhaust Temperature Sensor

In line with the introduction of the oxidation catalytic converter and the diesel particulate filter in one housing, only one exhaust temperature sensor upstream of the oxidation catalytic converter was used.

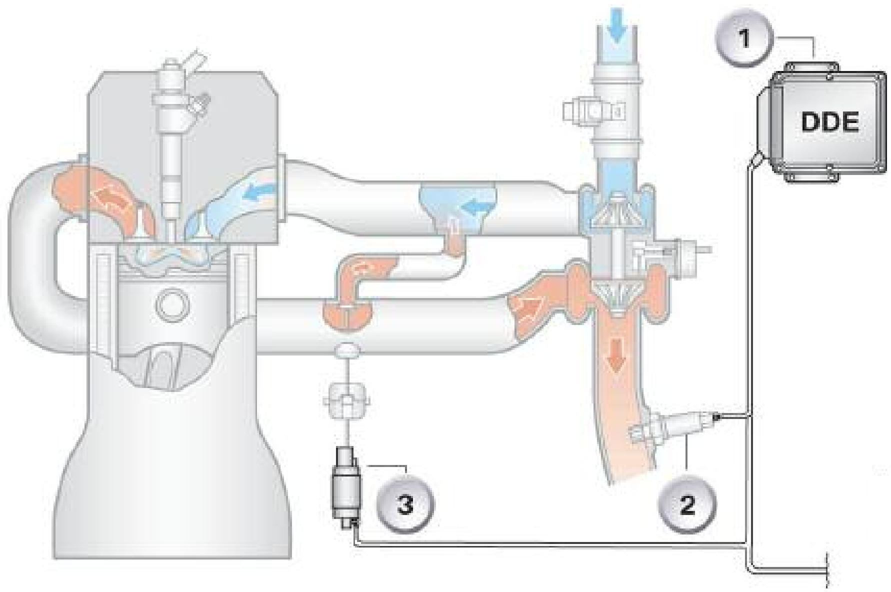
The sensor upstream of the diesel particulate filter is replaced by a characteristic map in the DDE. Currently, however, a second exhaust temperature sensor is again used upstream of the diesel particulate filter as the characteristic map cannot provide the required degree of accuracy.

Note: The electrical supply line must not be subjected to a pulling force of more than 80 N. Sensors that have been dropped must not be used again.

Oxygen Sensor

More stringent exhaust emission limits have rendered necessary more accurate control of the exhaust gasses. The mean quantity adaptation (MMA) makes it possible to comply with the specified limits with a corresponding safety margin.

This is necessary as the emission limits must still be maintained despite component tolerances and operating influences.



Index	Explanation
1	DDE
2	Oxygen Sensor
3	EGR Valve

With mean quantity value adaptation the fuel/air ratio (lambda) is adjusted by corresponding adaptation of the exhaust gas recirculation. This feature compensates for any inaccuracies relating to manufacturing tolerances of the hot-film air mass meter or of the fuel injectors.

An injection volume averaged across all cylinders is calculated from the fuel-air ratio measured by the oxygen sensor and the air mass measured by the HFM. This value is compared with the injection volume specified by the DDE.

If a discrepancy is detected, the fresh air mass is adapted to match the actual injection volume by correspondingly adjusting the EGR valve, thus establishing the correct fuel-air ratio.

The MMA is not an "instantaneous" regulation but an adaptive learning process. In other words, the injection volume error is taught into an adaptive characteristic map that is permanently stored in the control unit.

The MMA characteristic map must be reset with the aid of the BMW diagnosis system after replacing one of the following components:

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

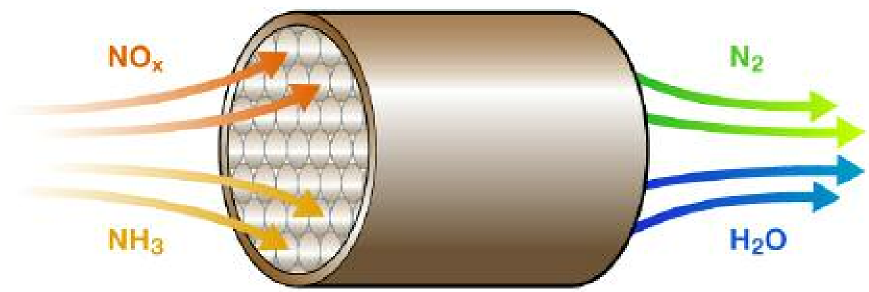
For optimum combustion, a diesel engine is operated with a fuel-air ratio of Lambda > 1, i.e. rich in oxygen. Lambda = 1 signifies a mixture of 1 kg fuel with 14.7 kg air.

The oxygen sensor is located at the inlet to the shared housing of the diesel particulate filter (DPF) and oxidation catalytic converter.

The oxygen sensor used on the M57D30T2 is the Bosch LSU 4.9 broadband oxygen sensor. It is installed before the DPF and DOC.

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.

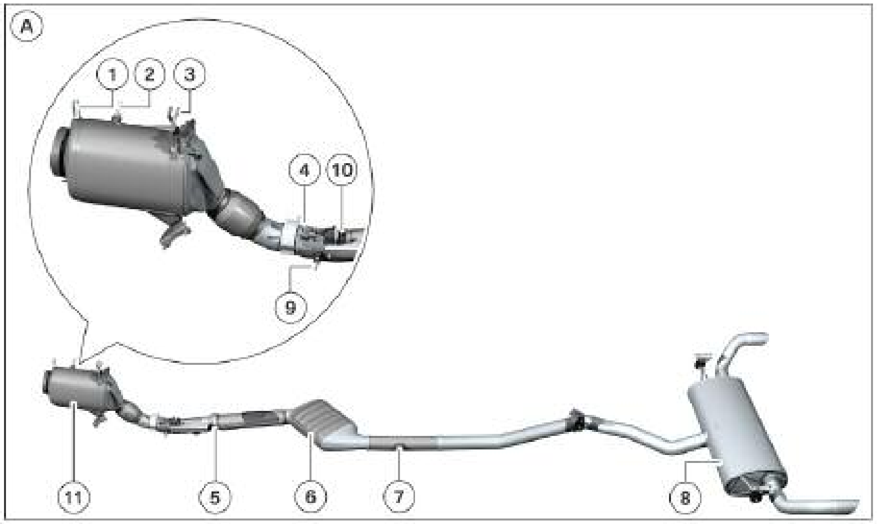
Another term which is used is AdBlue, which is the registered trademark for AUS32. However, there are other producers of AUS32. AdBlue is just one of them.

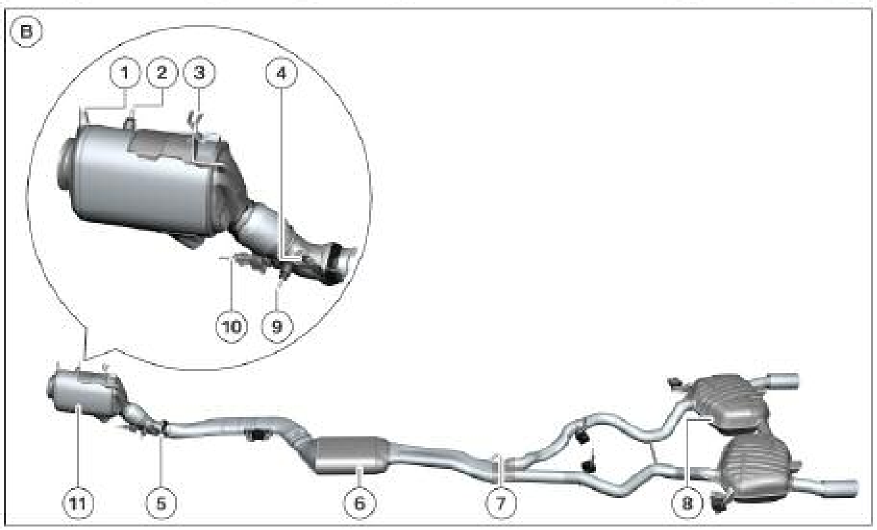
The AdBlue trademark is currently held by the German Association of the Automobile Industry (VDA), who ensure quality standards are maintained in accordance with DIN 70070 specifications.

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.





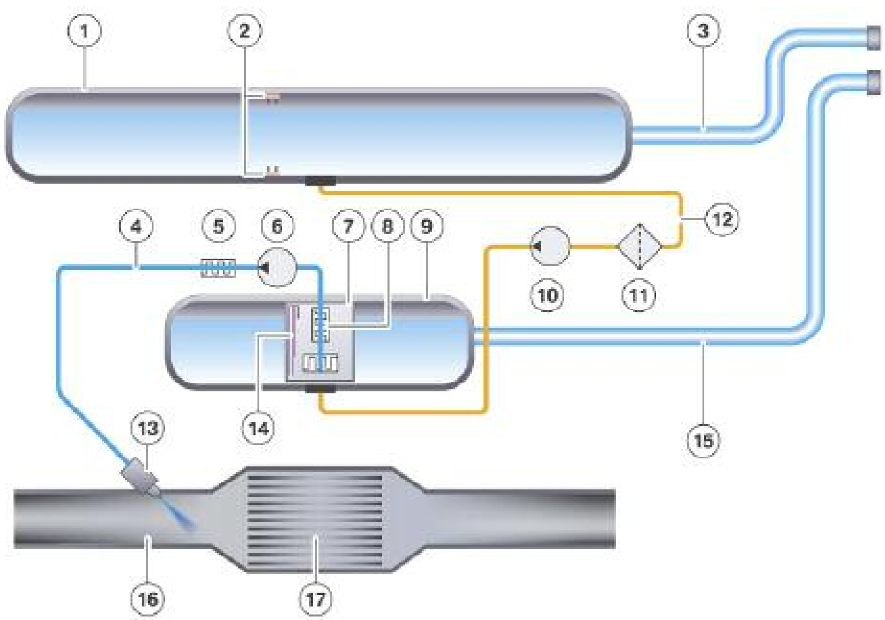
Index	Explanation	Index	Explanation
A	Exhaust system E70	6	SCR catalyst
B	Exhaust system E90	7	NO_X sensor after SCR catalyst
1	Oxygen sensor Exhaust gas temperature sensor before DOC (concealed)	8	Rear silencer (muffler)
2	Exhaust gas temperature sensor after DOC	9	Exhaust gas temperature sensor after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

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:



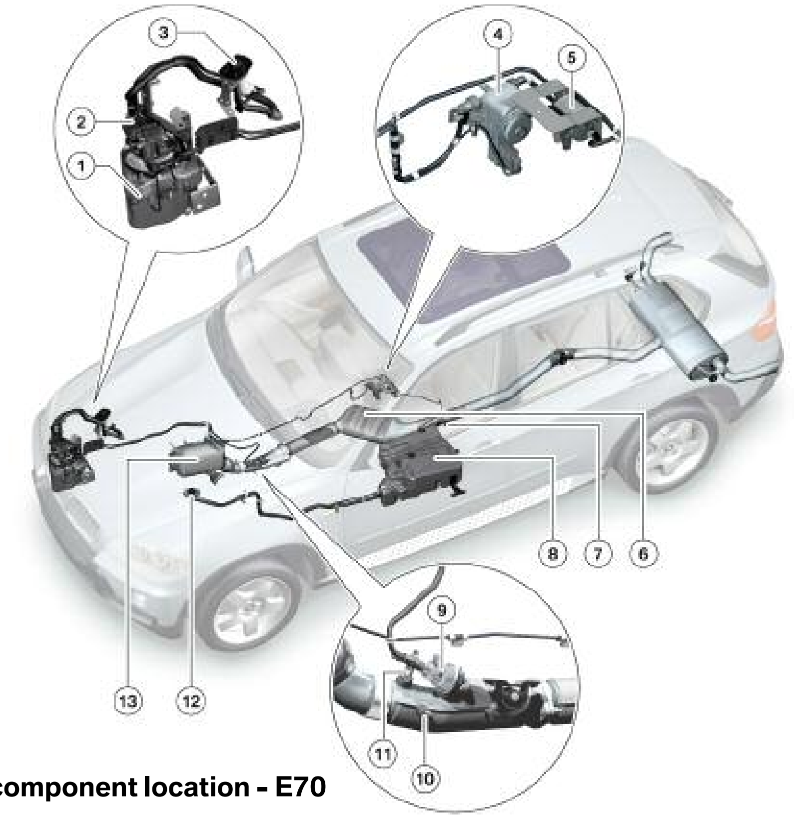
Index	Explanation	Index	Explanation
1	Passive reservoir	10	Transfer pump
2	Level sensors	11	Filter
3	Filler pipe, passive tank	12	Transfer line
4	Metering line	13	Metering module
5	Metering line heater	14	Level sensor
6	Pump	15	Filler pipe, active reservoir
7	Function unit	16	Exhaust system
8	Heater,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

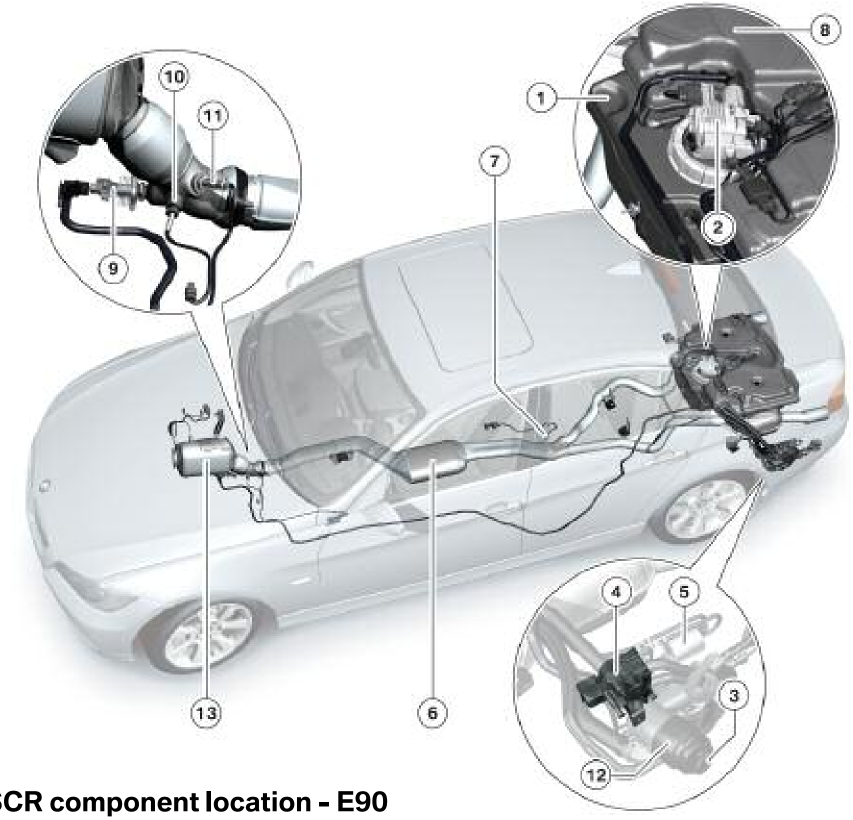


SCR component location - E70

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.

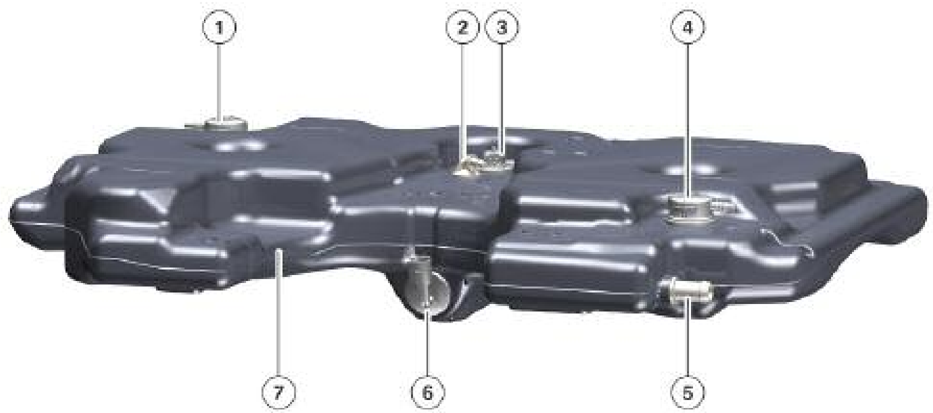
The fillers are located on the left-hand side behind the rear wheel where they are accessible through an opening in the bumper panel. The fillers are arranged in the same way as the reservoirs, i.e. the lower most is the filler for the active reservoir. The transfer unit and the filter are located behind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

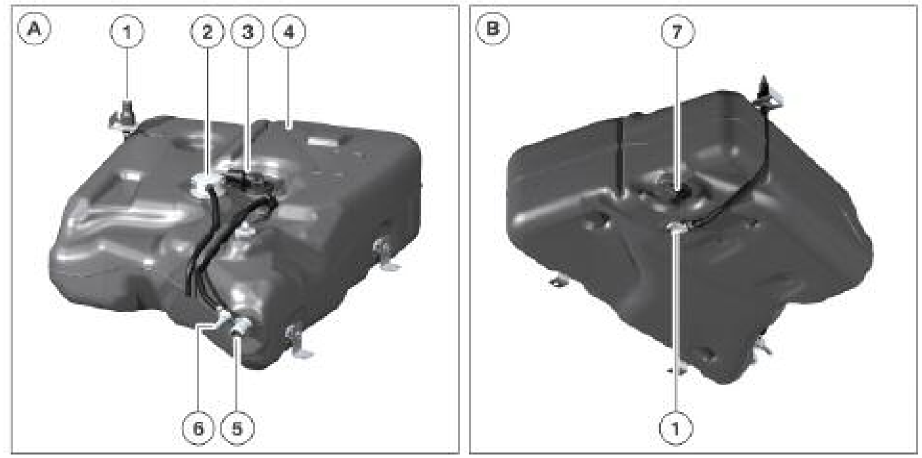
The following components make up the passive reservoir:

- 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.

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

Active reservoir - E90

Active reservoir - E70

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

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

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.

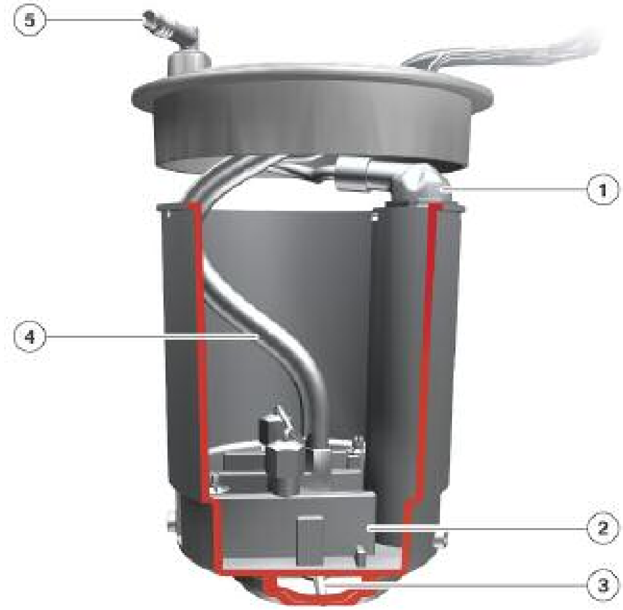
Unlike a surge chamber in the fuel tank, the lower section of the function unit has slots. This chamber creates a smaller volume in the reservoir that scarcely mixes with the urea-water solution outside the chamber.

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.

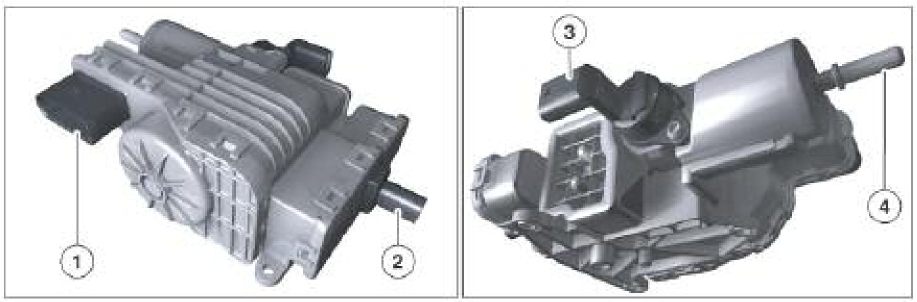
Three contacts are responsible for signalling the different levels. The fourth contact is the reference, i.e. the contact via which the electric circuit is closed. This reference contact cannot be seen in the figure as it is located directly behind the "Empty" contact (3).

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

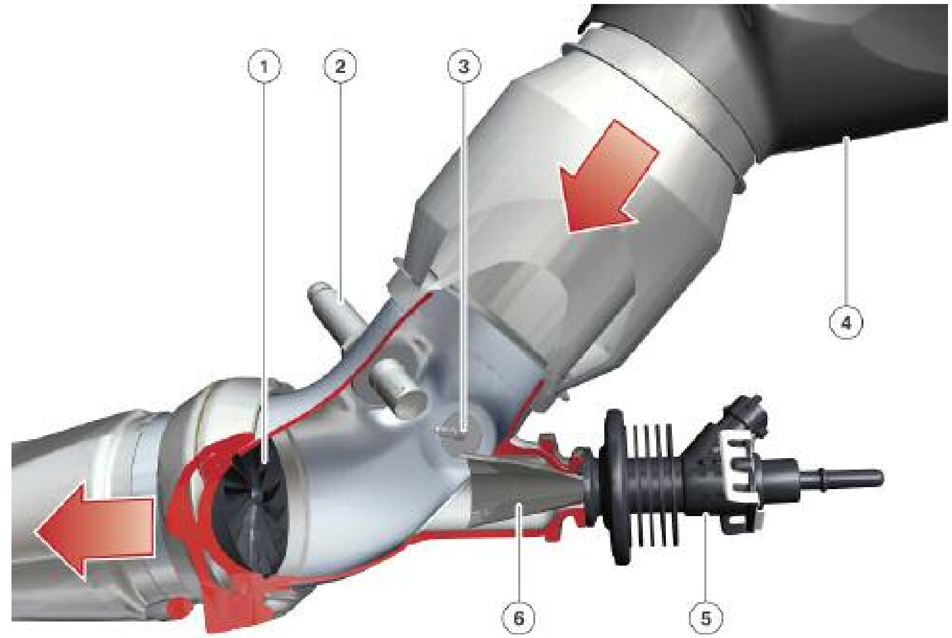
The metering module is responsible for injecting the urea-water solution into the exhaust pipe. It features a valve that is similar to the fuel injector in a petrol engine with intake manifold injection.

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.

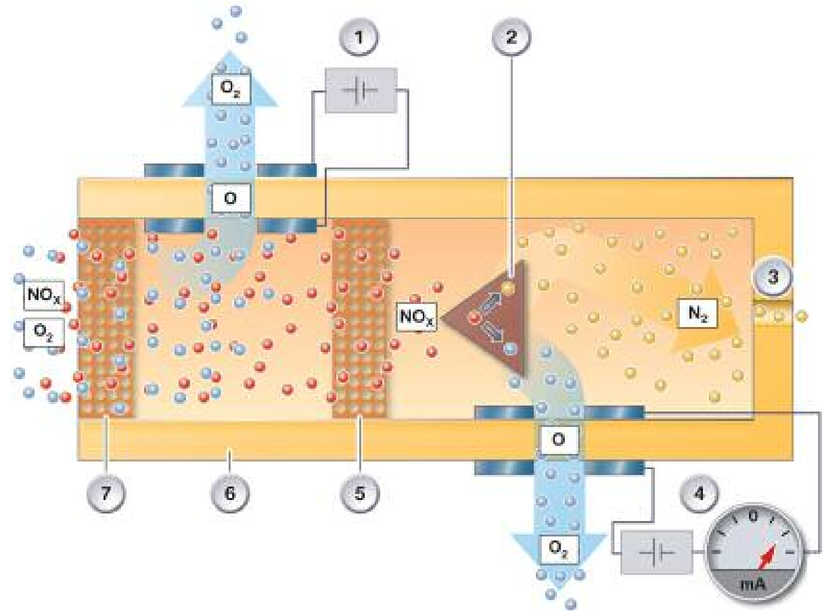
The exhaust gas flows through the NO_x sensor. Here, only oxygen and nitrogen oxides are of interest. In the first chamber, the oxygen is ionized out of this mixture with the aid of the first pump cell and passed through the solid electrolyte.

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.

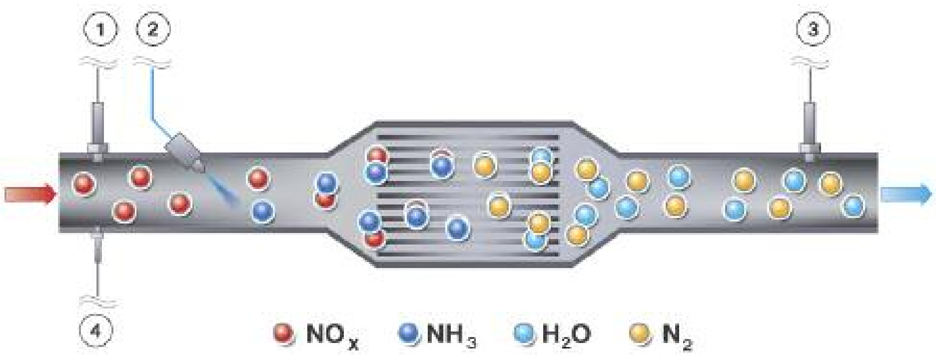
The following graphic shows the functional principle of this measuring system.



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).

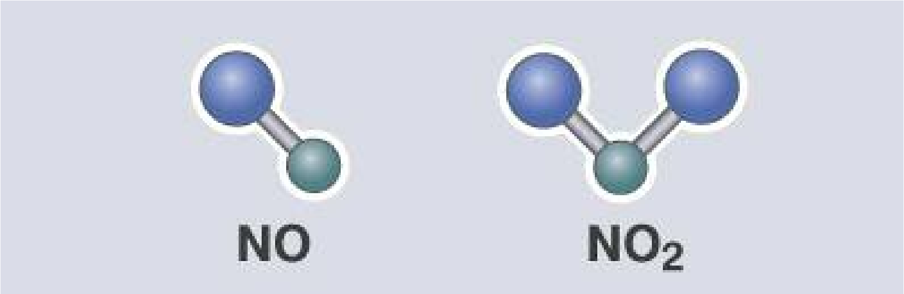
A further NO_X sensor that monitors this function is located downstream of the SCR catalytic converter.

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).

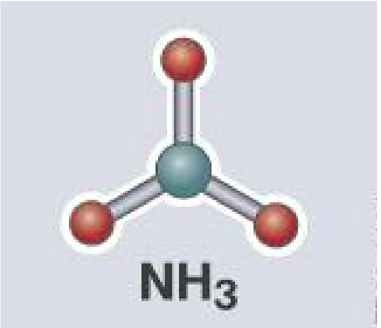
Chemical Reaction

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.



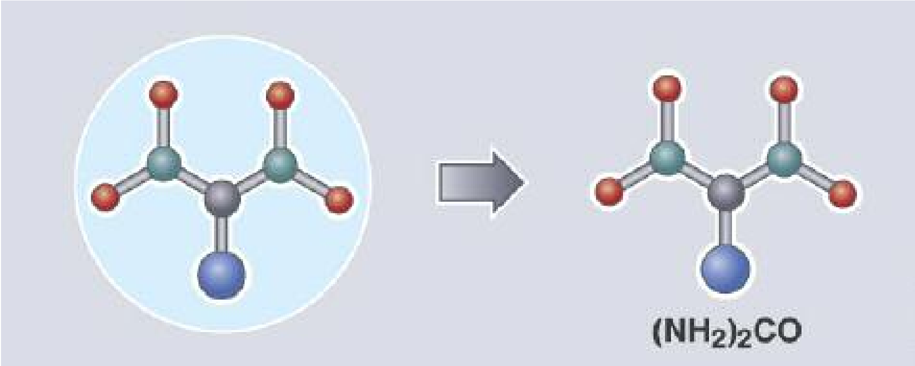
Urea-water solution

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.

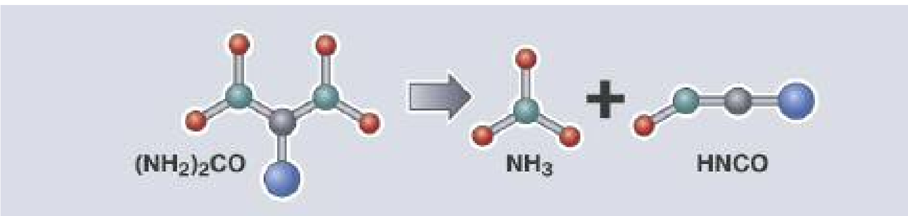
Initially, the urea ($(NH_2)_2CO$) dissolved in the urea-water solution is released. The conversion of urea into ammonia takes place in two stages.



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:	$(NH_2)_2CO > NH_3 = HNCO$

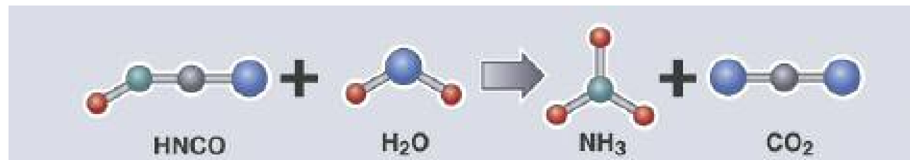
Thermolysis: Urea converts to ammonia and isocyanic acid



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:	$HNCO + H_2O > NH_3 + CO_2$

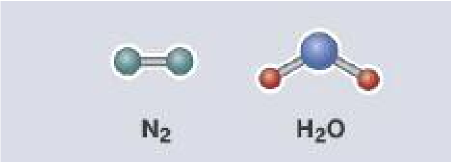
Hydrolysis: Isocyanic acid reacts with water to form ammonia and carbon dioxide



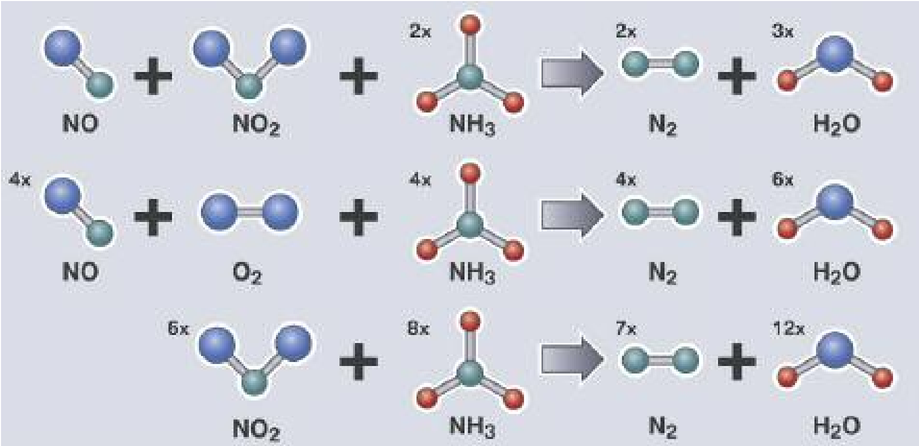
The water required for this purpose is also provided by the urea-water solution. Therefore, following hydrolysis, all the urea is converted into ammonia and carbon dioxide.

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

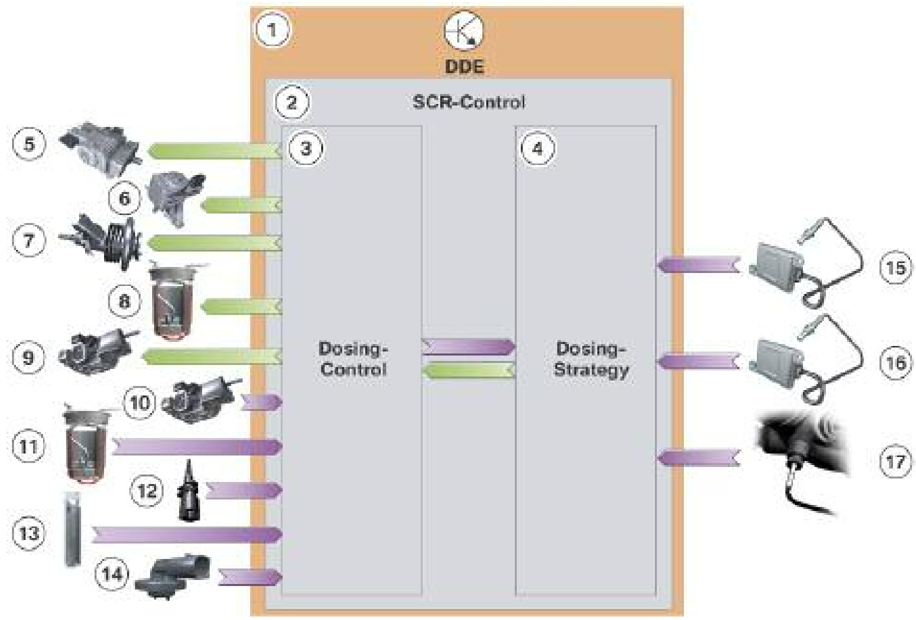
It can be seen that each individual atom has found its place again at the end of the process, i.e. exactly the same elements are on the left as on the right.

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

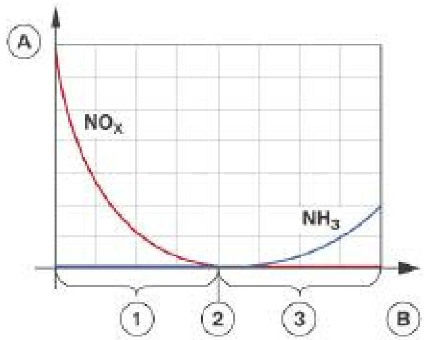
The SCR control is integrated in the digital diesel electronics (DDE). The SCR control is divided into the metering system control and the metering strategy.



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.

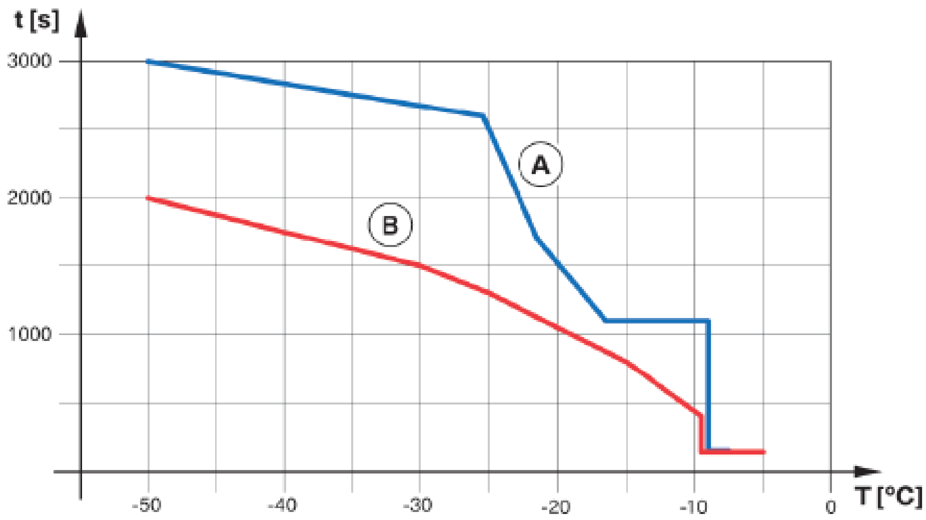
This time is constant from -9°C to -16.5°C as it is not possible to determine to what extent the urea-water solution is frozen.

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.

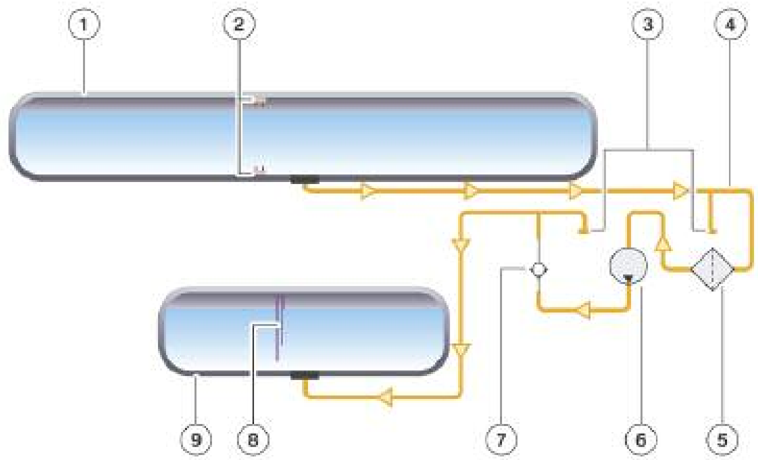
The delay time that is initiated by the temperature in the active reservoir is approximately 18 minutes while the delay time initiated by the ambient temperature is 25 minutes. Since the delay time initiated by the ambient temperature is longer, this will give rise to a longer delay.

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.

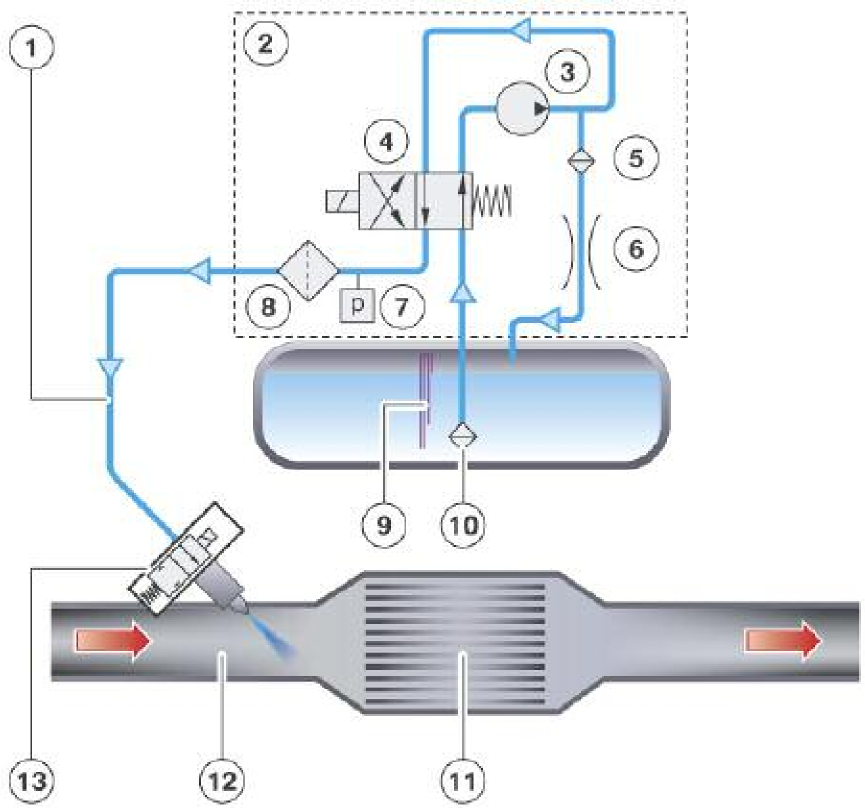
This function determines whether the system has been filled with the wrong medium as it is present in high concentration in the active reservoir.

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		

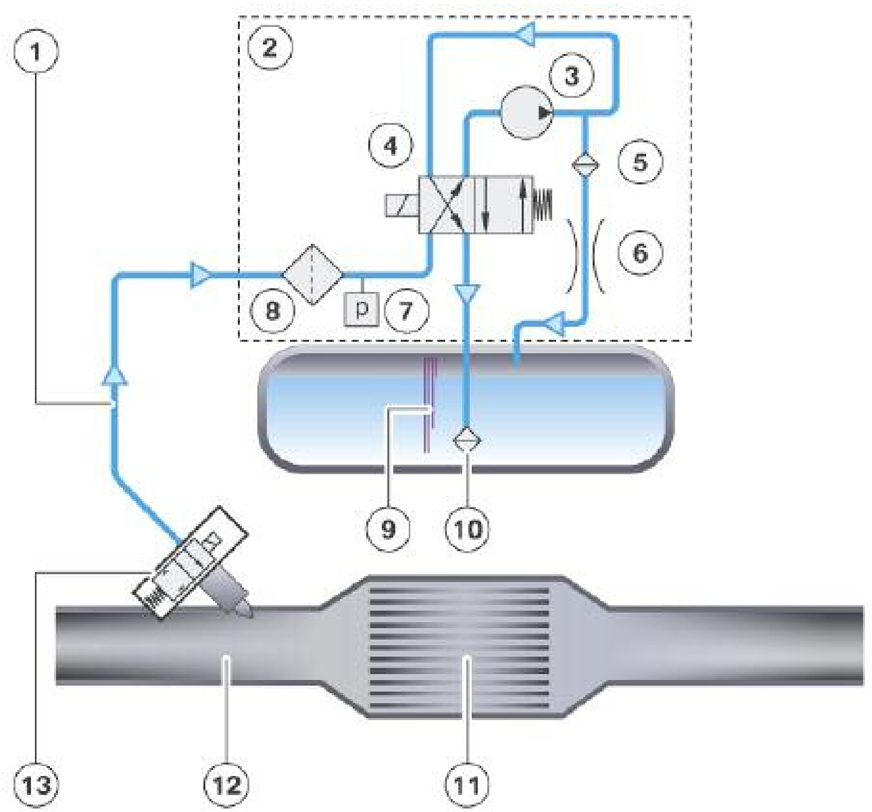
The pump is actuated by a pulse-width modulated signal (PWM signal) from the DDE. The PWM signal provides a speed specification for the purpose of establishing the system pressure. The value for the speed specification is calculated by the DDE based on the signal from the pressure sensor.

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

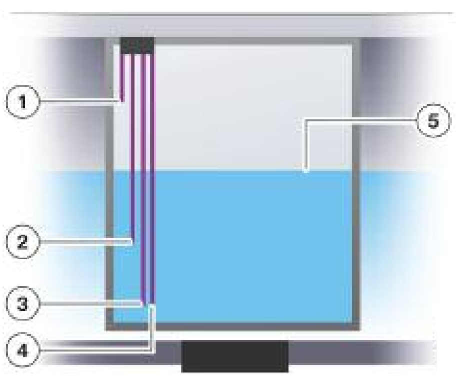
There are level sensors both in the active as well as in the passive reservoir. However, these sensors are not continuous sensors as in the fuel system for example. They can determine only a specific point, to which a defined quantity of urea-water solution in the reservoir is assigned.

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.

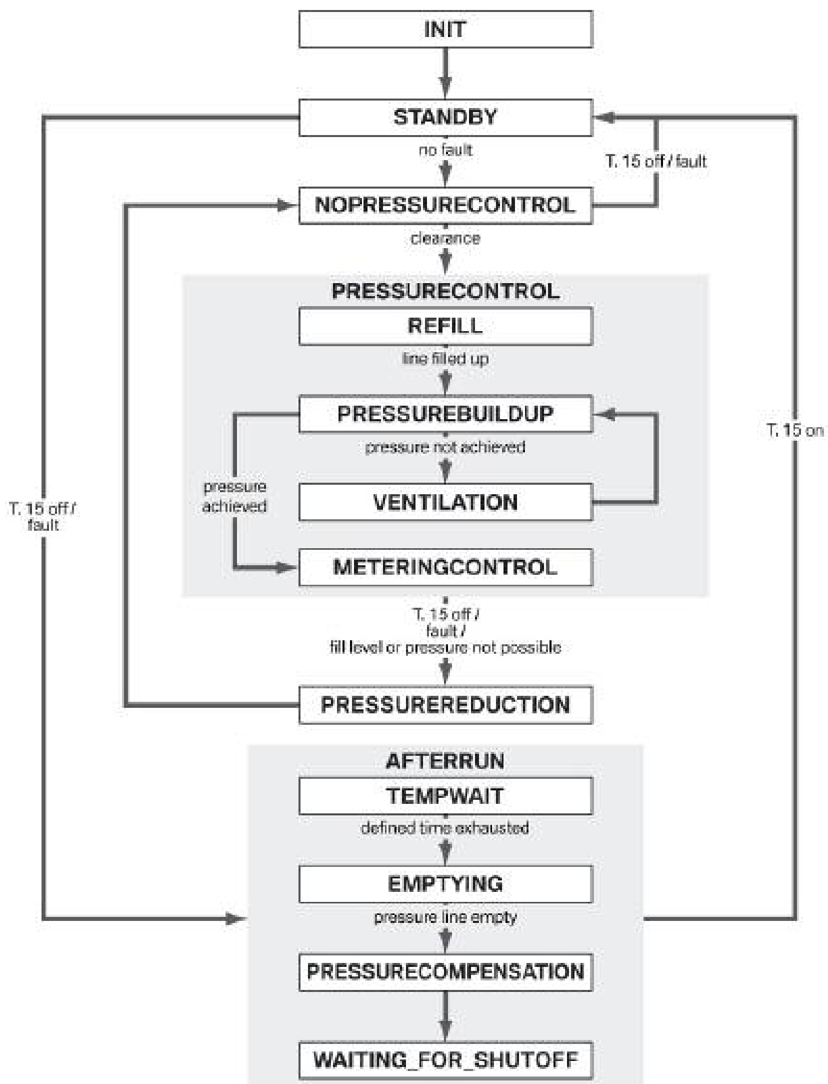
Normally, the level then drops below the next lower level sensor at the same time as determined by the level calculation. An adjustment takes place at this point and the calculation is restarted.

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.

NO PRESSURE CONTROL
(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.

PRESSURE CONTROL (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.

- **PRESSURE BUILDUP**

  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.

- **METERING CONTROL**

  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.

PRESSURE REDUCTION
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.

- **PRESSURE ---COMPENSATION (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

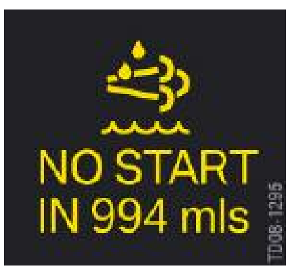
The warning scenario begins when the level drops below the "Warning" level sensor in the active reservoir. At this point, the active reservoir is still approximately 50% full with urea-water solution. The level is then determined as a defined volume (depending on type of vehicle).

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.

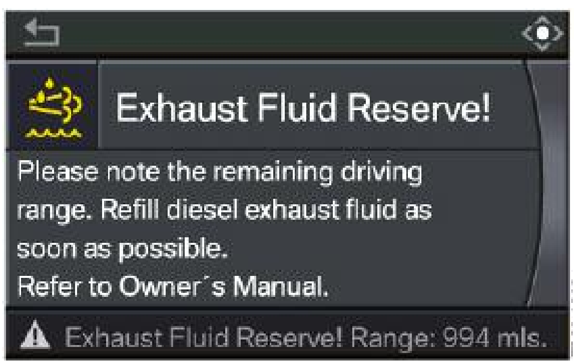
A countdown from 1000 mls now takes place irrespective of the actual consumption of the urea-water solution. The driver receives a priority 2 (yellow) check control message showing the remaining range.

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:

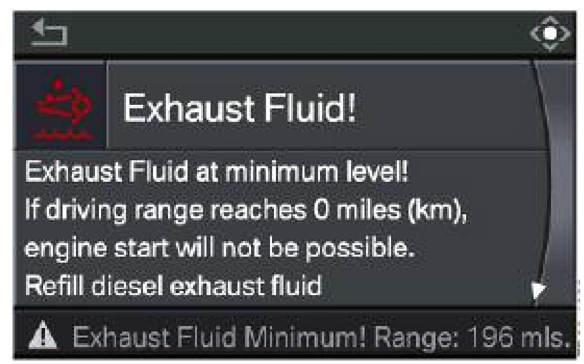


CC message in cluster, range < 1000 miles



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.

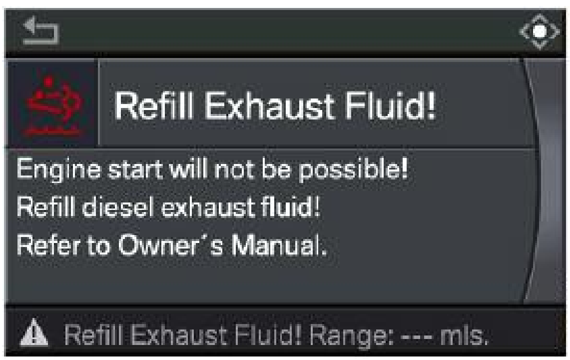
If the system is refilled only after engine start has been disabled, the logic of the refill recognition system is changed in this special case, enabling faster refill.

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.

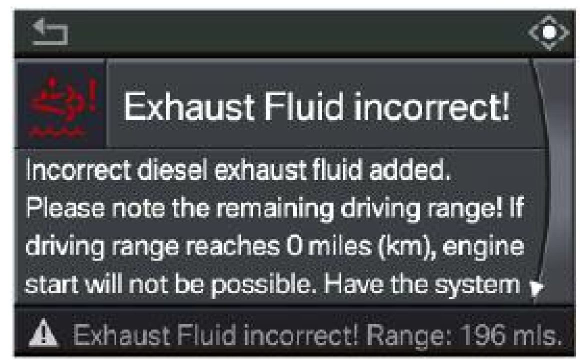
The exclamation mark in the symbol identifies the fault in the system. In this case, the message in the CID informs the driver to go to the nearest workshop.

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.

NOTES PAGE

NOTES PAGE

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

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.

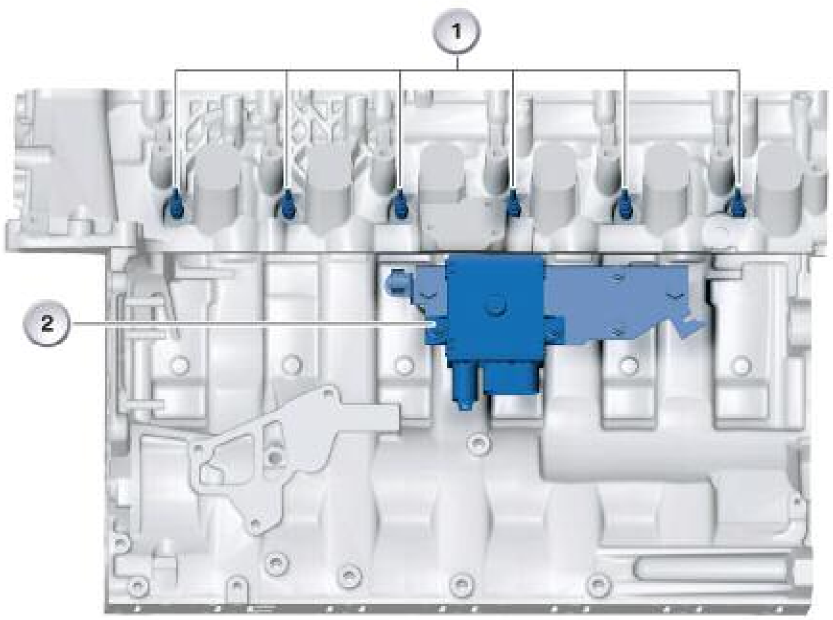
Each of these faults is stored reversible. If the fault is determined in two successive driving cycles, an irreversible fault is stored and the MIL is activated.

Glow-plug System

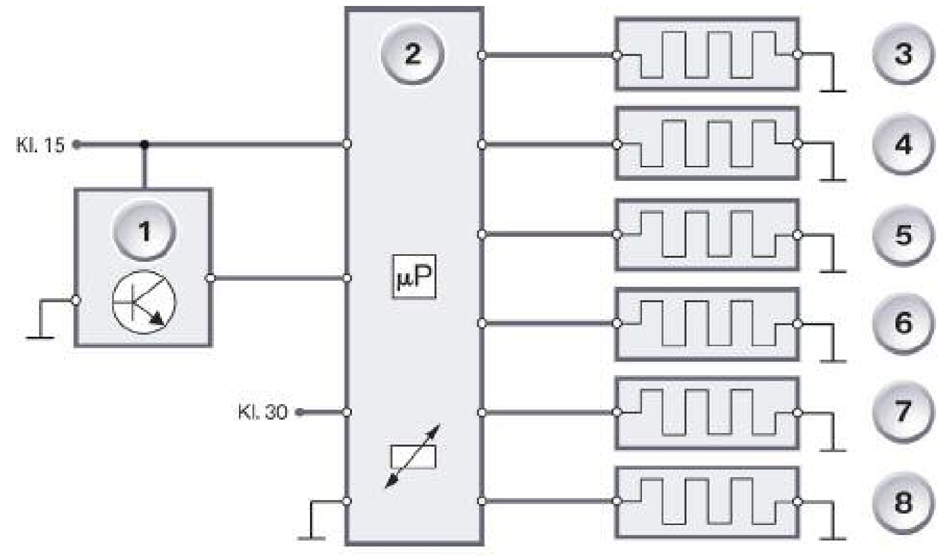
The glow-plug system is responsible for providing reliable cold start properties and smooth operation when the engine is cold.

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.

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.

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.

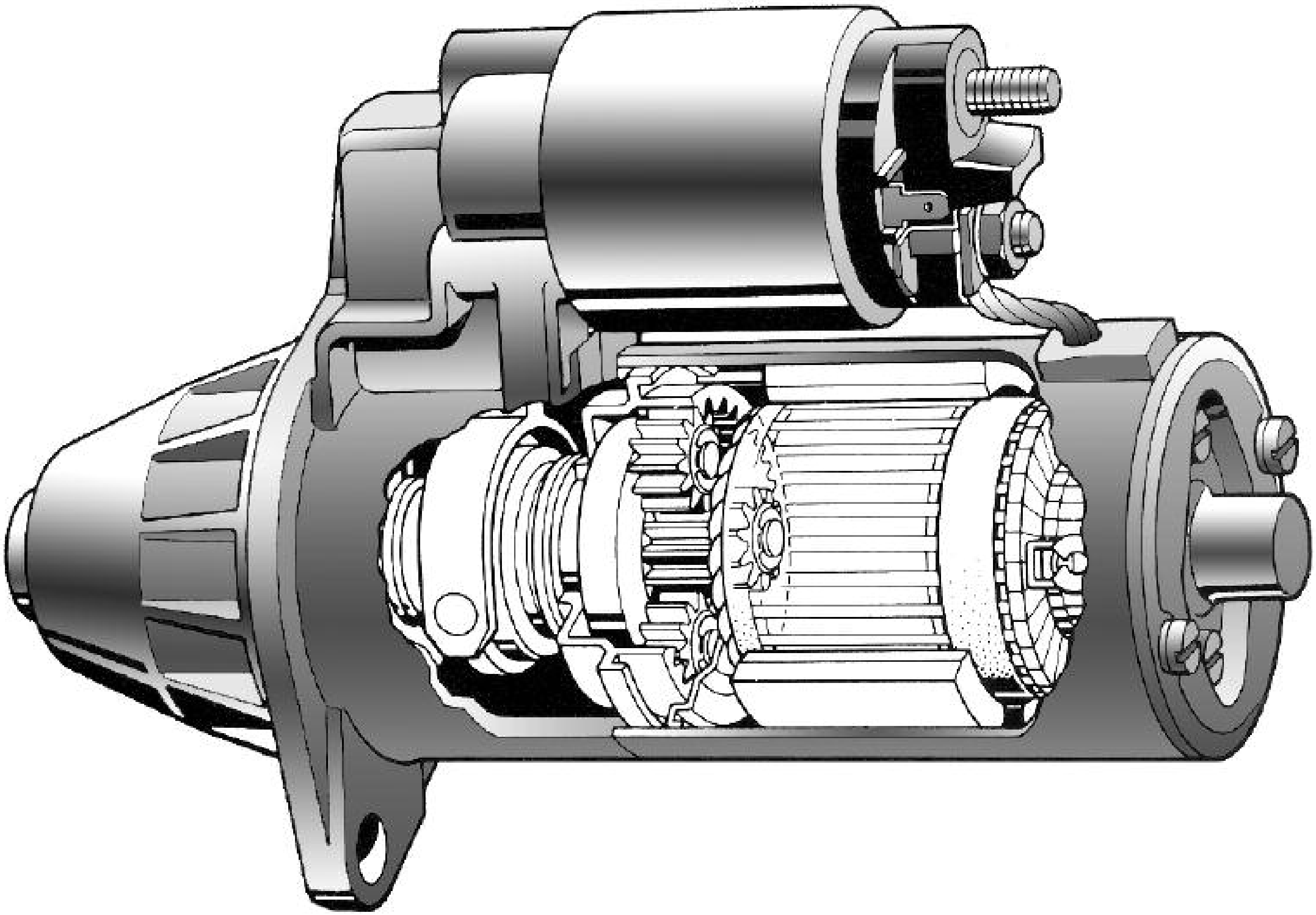
Start heating is terminated:

- 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.

Diesel Starter

Diesel engines have a much higher compression ratio than gasoline engines and therefore require more torque when cranking. Since diesel engines rely on the heat of compression to run, there must be sufficient cranking speed when starting.

To provide sufficient torque, starters on BMW diesel engines are specially designed. The drive mechanism consists of a planetary gear set, to multiply torque in an efficient and compact manner.



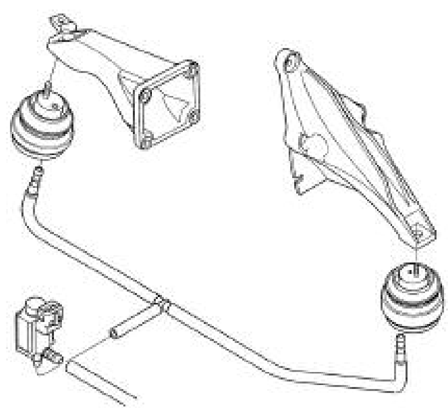
Vibration Reduction

Diesel engines have some inherent vibration concerns particularly during shutdown and startup phases. The engine mount control system provides a vacuum controlled motor mount system which can create a “hard” or “soft” setting based on engine and vehicle speed.

The motor mounts are controlled via a vacuum solenoid which is electrically controlled by the DDE.

Engine Mount Control

The engine mount control function of DDE actuates the electric changeover valve (EUV) for the variable-damping engine mounts.



The engine mount is set to the "soft" setting for engine starts. When the start phase times out the engine mount changeover takes place as a function of operating point and with an engine-speed-related hysteresis and a road speed-related hysteresis.

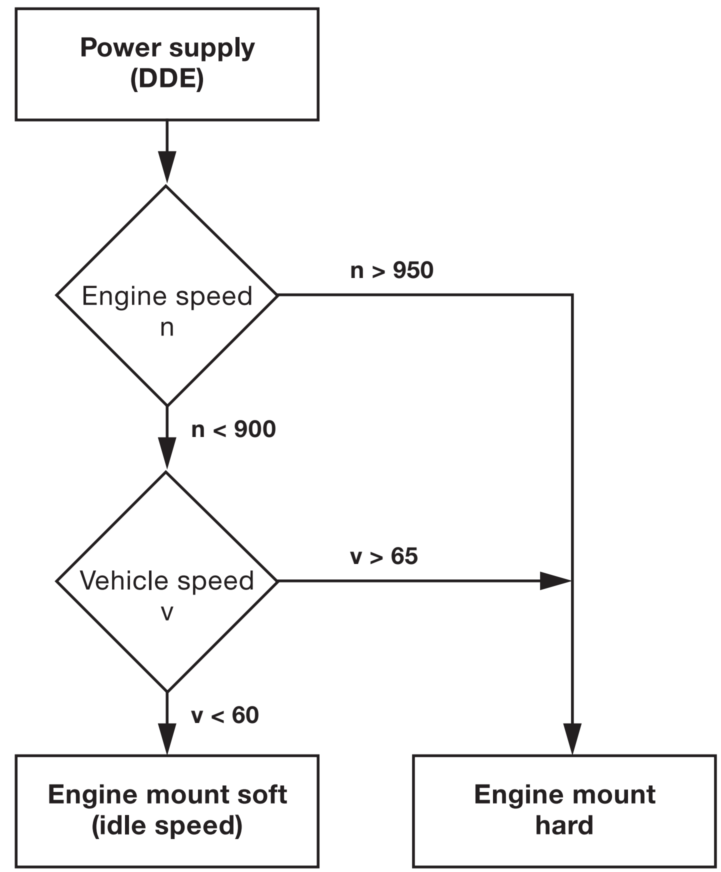
The default position is the “hard” setting when no vacuum is present at the engine mounts.

Aside from engine speed and road speed, coolant temperature can also modify the RPM parameters between 1100 and 1200 RPM.

Activation of the damping-controlled hydraulic mounts by the DDE is based on the following parameters:

Engine Mount Function

	Switching value	Remarks
Engine speed	900 rpm	Hysteresis (+ 50 rpm)
Vehicle speed	60 km/h	Hysteresis (+ 5 km/h)



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.

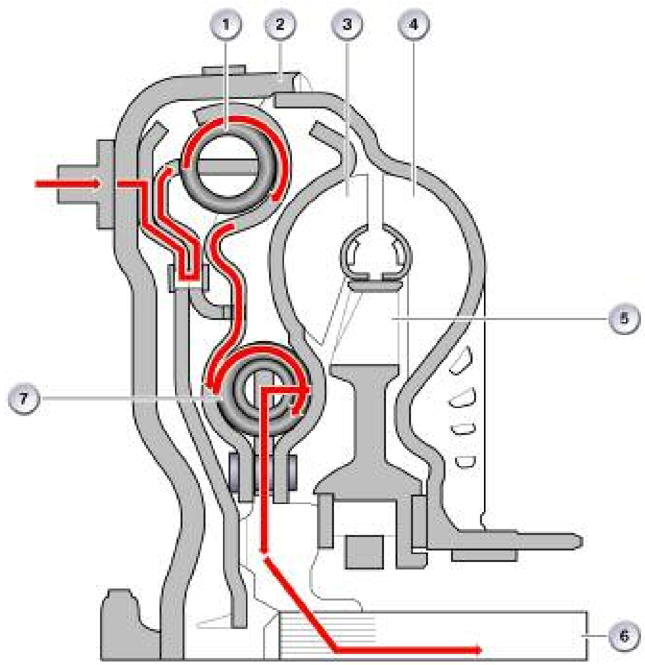
A so-called turbine torsional damper (TTD) is used while a twin damper torque converter is used for diesel engines.

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.

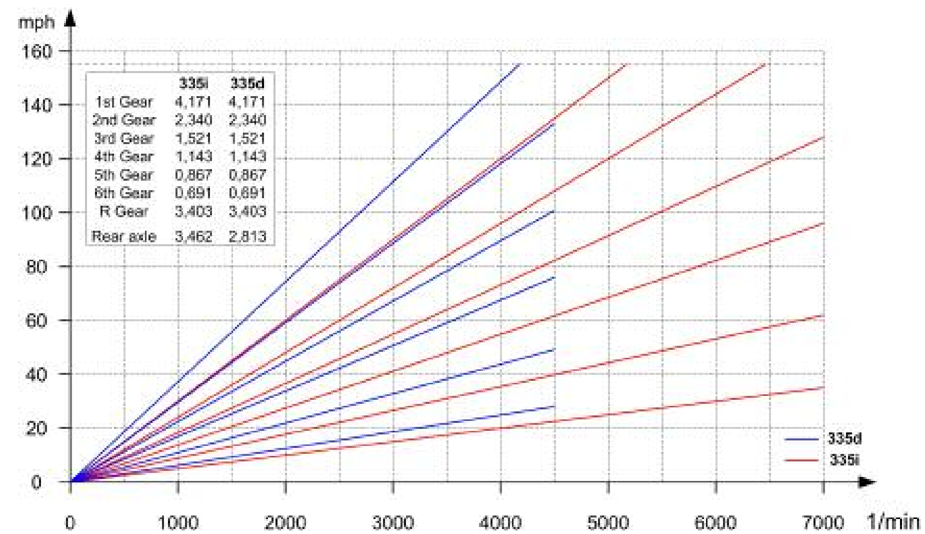
These further improved damping properties effectively adapt the transmission to the operational irregularities of the diesel engine.

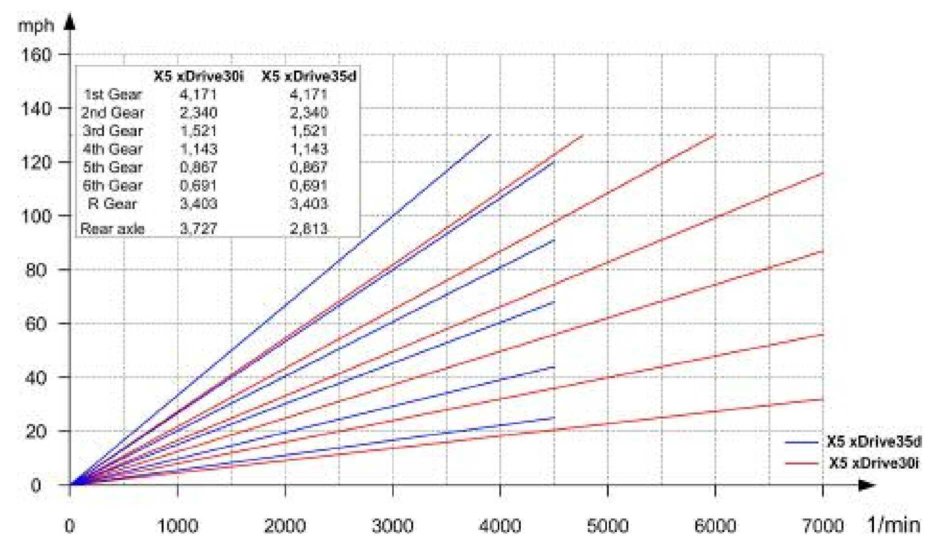


Index	Explanation	Index	Explanation
1	Annular spring	5	Stator
2	Converter housing	6	Transmission input shaft
3	Turbine wheel	7	Annular spring assembly
4	Impeller		

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

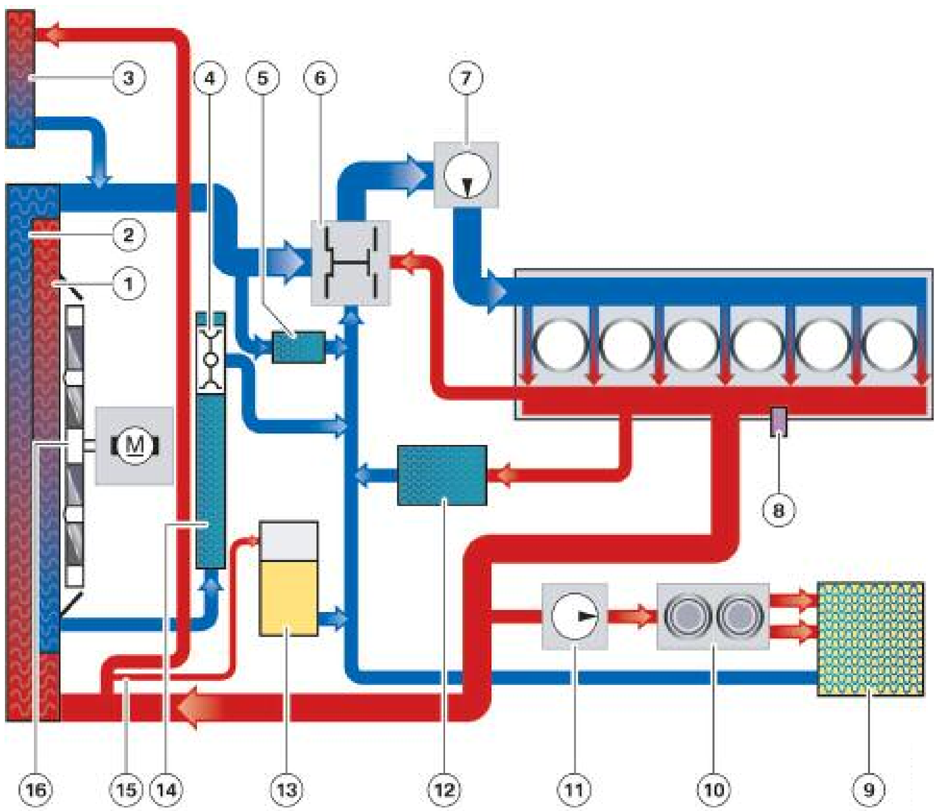
The cooling system, is in part, vehicle-specific. In principle, there are scarcely any differences between the cooling systems on petrol and diesel engines.

The two basic differences compared to a gasoline engine are:

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

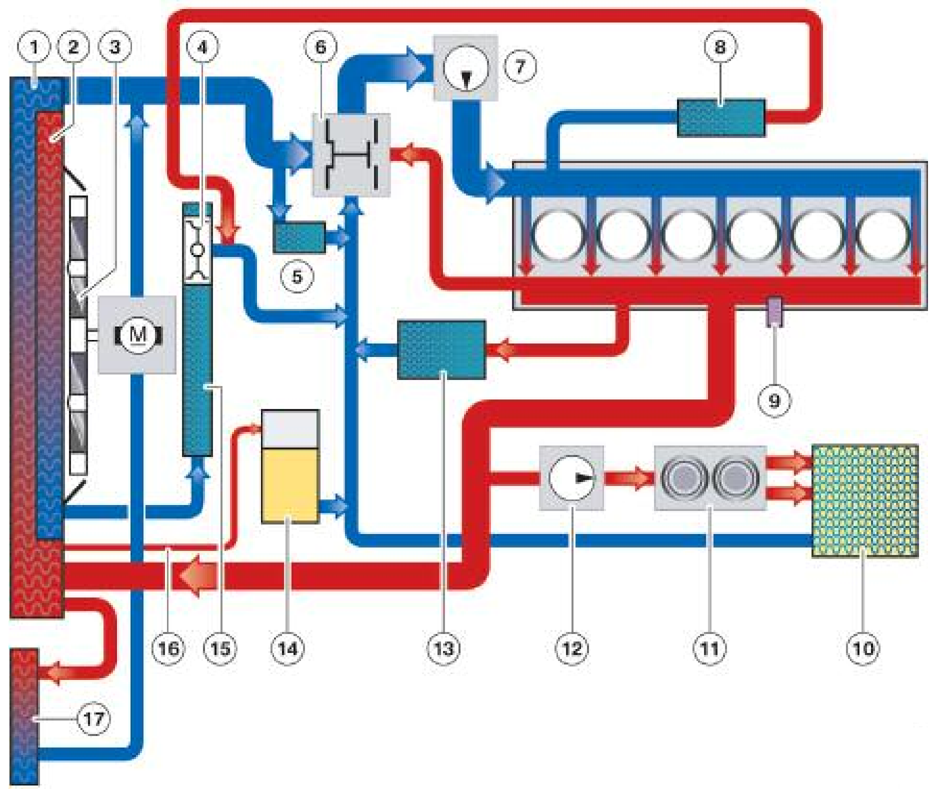
The E70 and E90 differ with regard to the EGR cooler. Since the E70 is equipped with a low pressure EGR system, it has a second EGR cooler, the low pressure EGR cooler.

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.

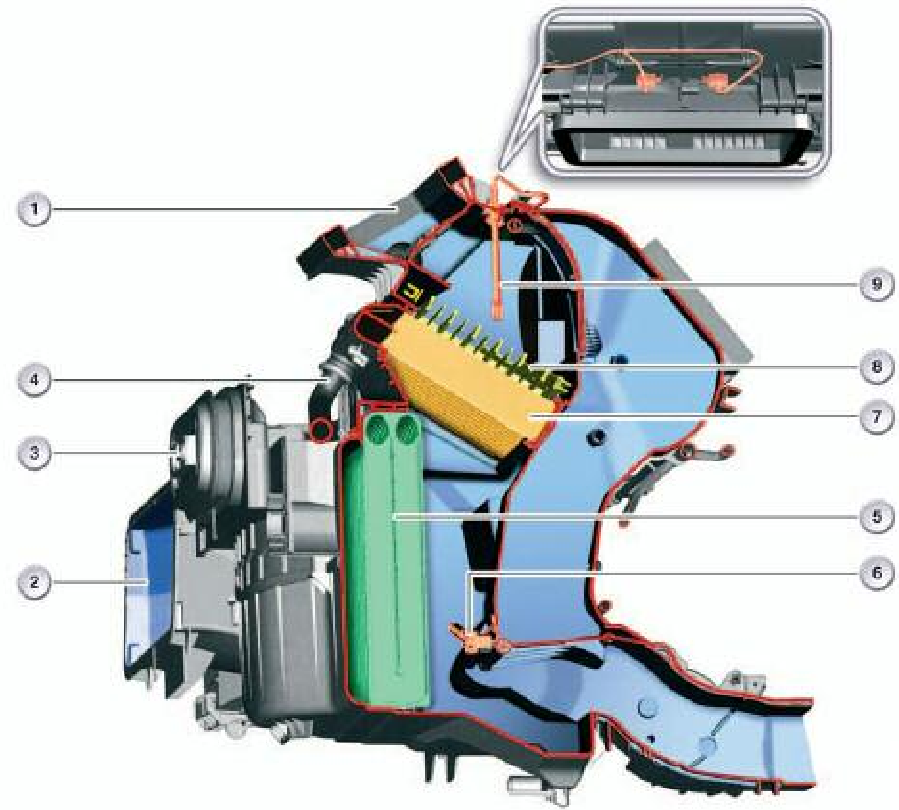
This is connected to the IHKA via the LIN bus and is controlled between 0 - 100% when heating is required (infinitely variable). The electric PTC auxiliary heater may only be operated using excess alternator power.

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:

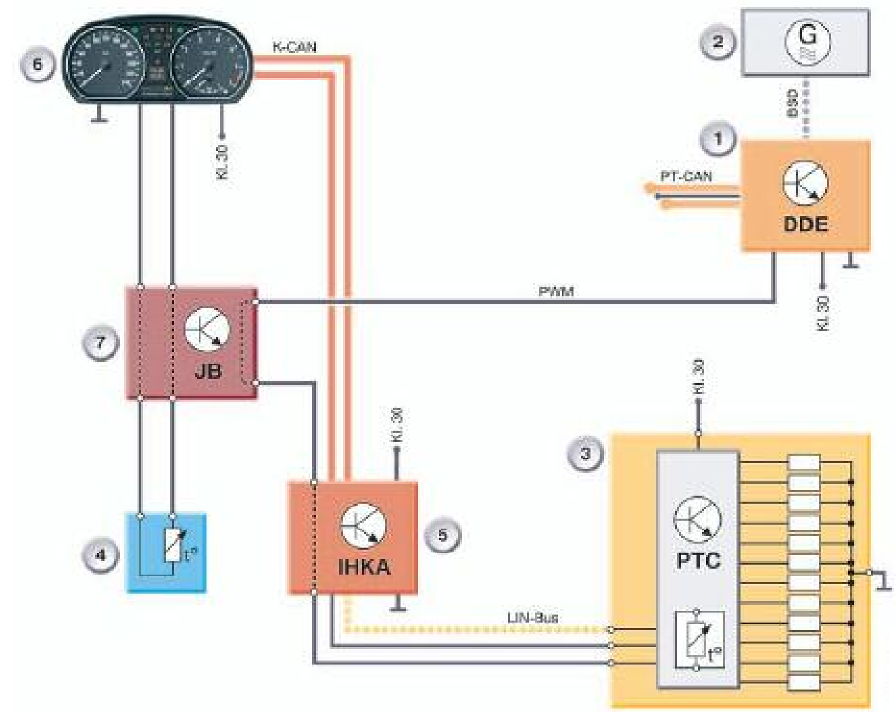
- Presence of power supply, terminal 15 and power supply voltage measurement
- Power output stage fault

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.

NOTES PAGE