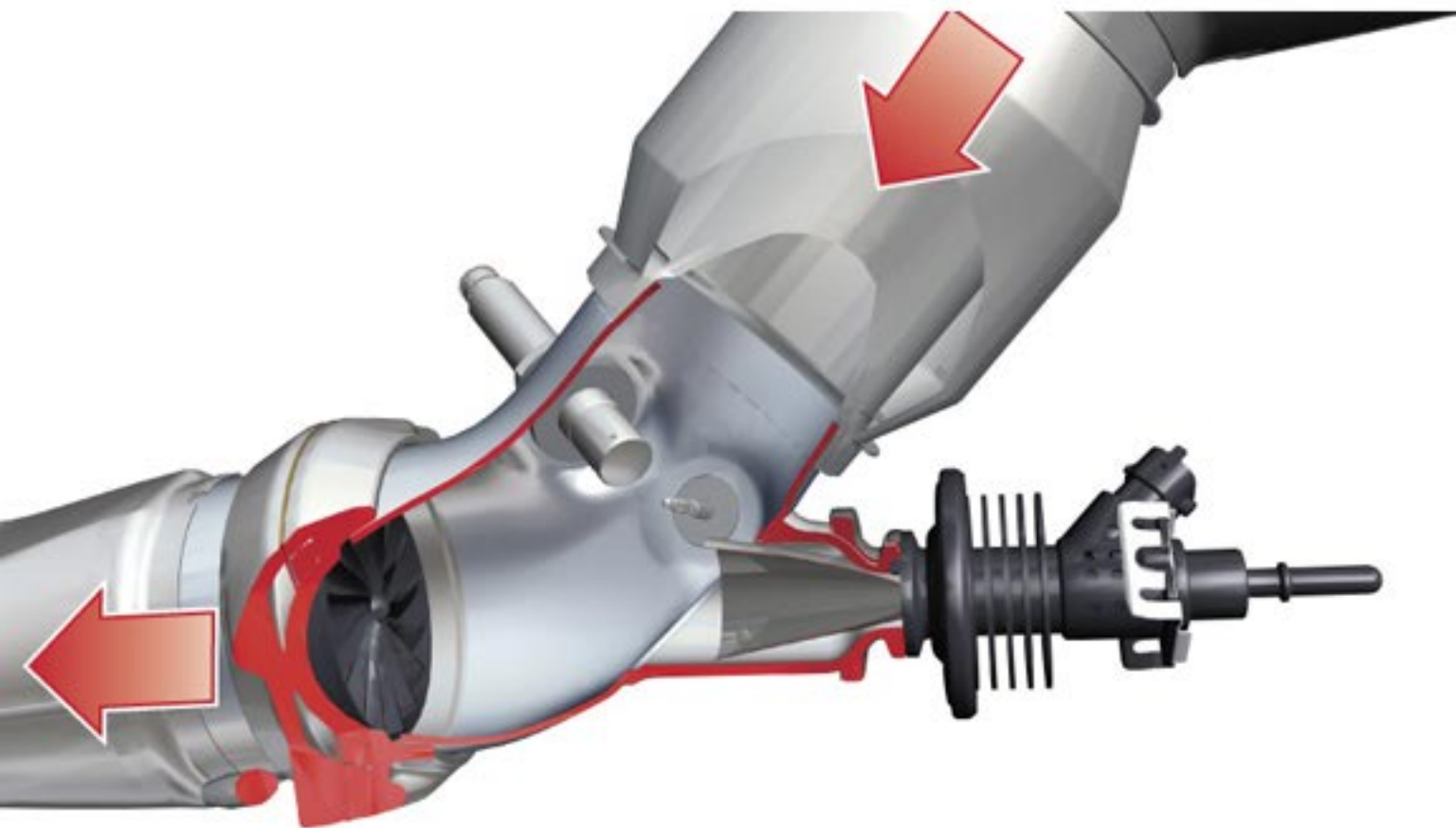


Reference Manual



DIESEL TECHNOLOGY



Technical Training

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Introduction to 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 CO₂ emissions without a compromise in performance.

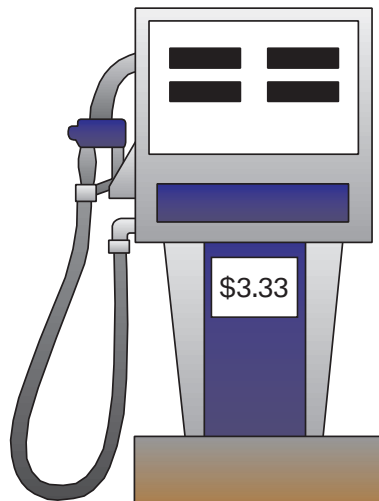
The new diesel BMW's offer two features which, together, are not usually associated with diesel engines or spoken in the same sentence - Performance and Efficiency.

Why did the diesels disappear from the US Market?

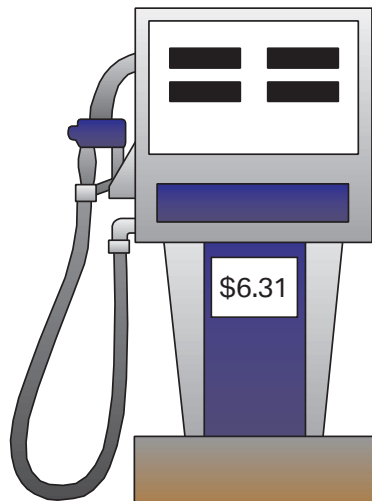
In the US market, diesel vehicles have not had much success over the last 20 years. Most of this is due to customer perception and the relatively low cost of gasoline.

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 CO₂ 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 CO₂ 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.

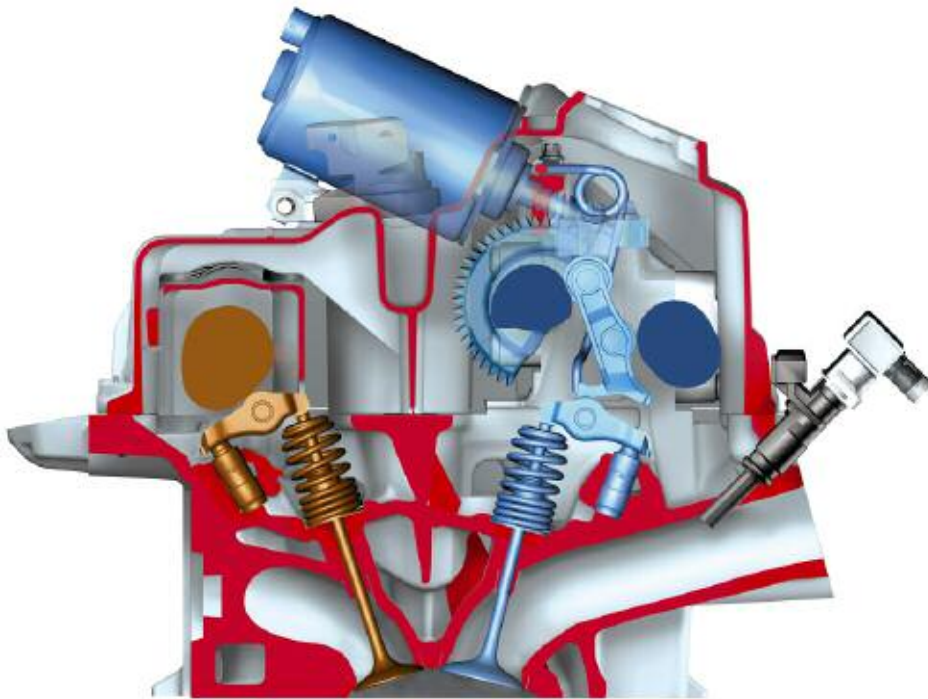
The “Hydrogen 7” has a V-12 internal combustion engine which takes advantage of one of the most plentiful and “eco-friendly” resources on Earth - Hydrogen. Using hydrogen as an automotive fuel is not an entirely new concept for BMW. These ideas have been in development by BMW since the 1970’s.

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 cm ³
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 CO₂ 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.



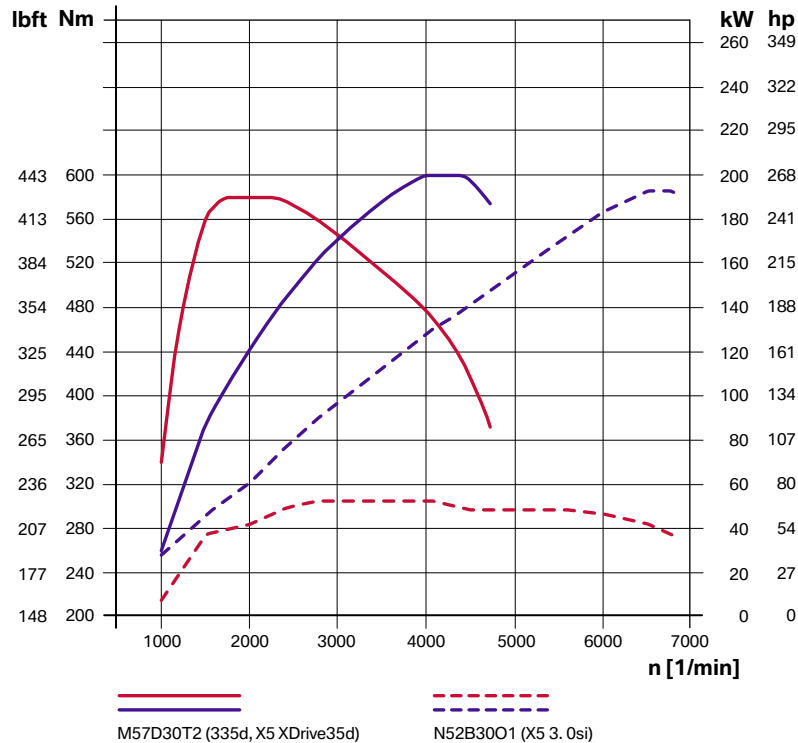
The following pages contain a comparison of the new BMW diesel engine technology to the current BMW gasoline engine technology.

Technical Data Comparison

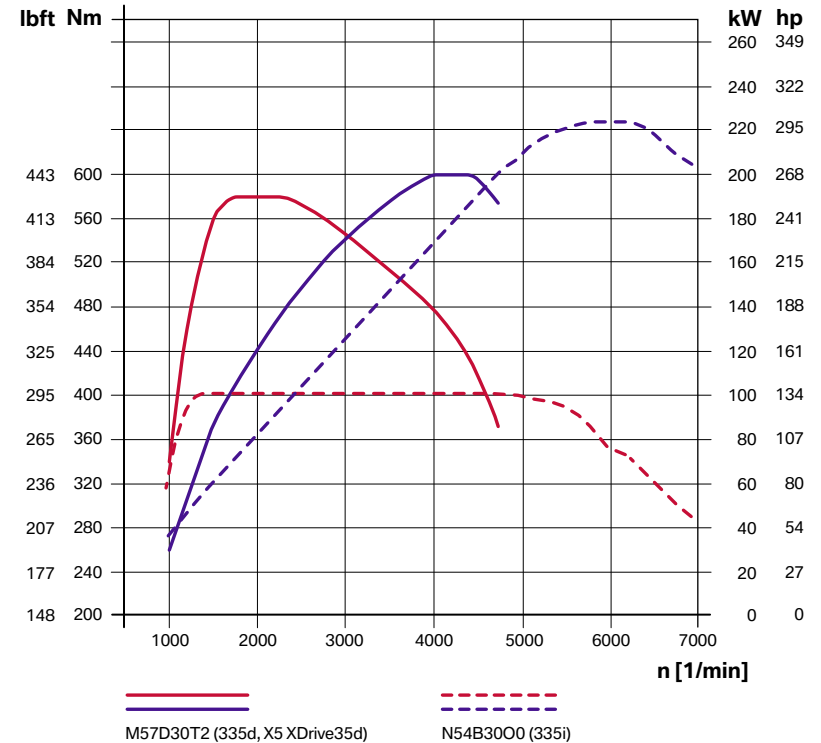
Description	Units of Measurement	N52B3001	N54B3000	N62B4801	M57D30T2 (US)
Engine type		R6	R6	V-8	R6
Displacement	(cm ³)	2996	2979	4799	2993
Firing order		1-5-3-6-2-4	1-5-3-6-2-4	1-5-4-8-6-3-7-2	1-5-3-6-2-4
Stroke	mm	88	88.9	88.3	90
Bore	mm	85	84	93	84
Power output @ rpm	hp @ rpm	260@6600	300 @ 5800	360 @ 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.

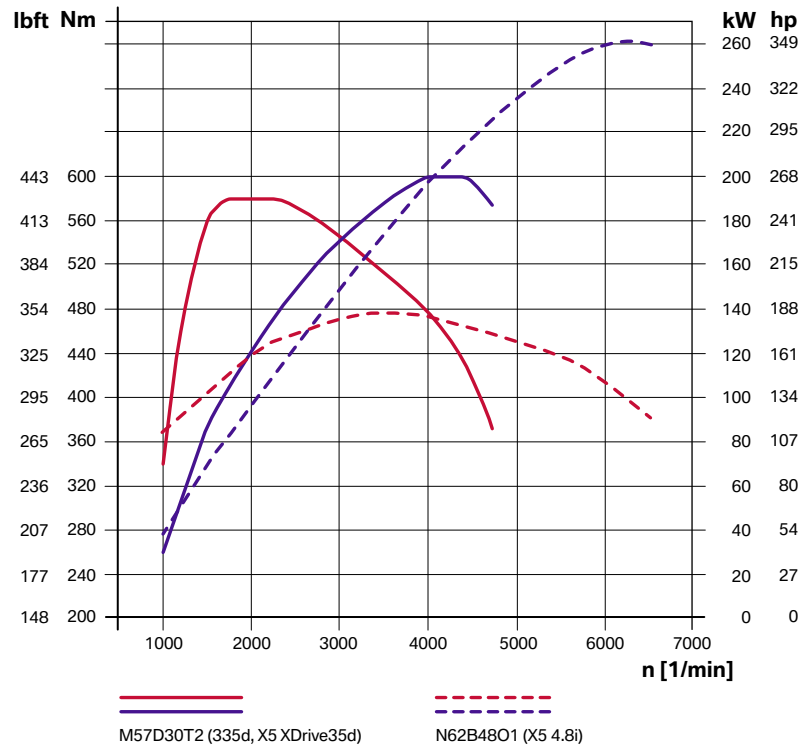
Most notably, the diesel has the advantage in the torque output. The above comparison shows a comparison between the N52 engine, which is a naturally aspirated 3-liter gasoline engine.

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 the 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 its 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:

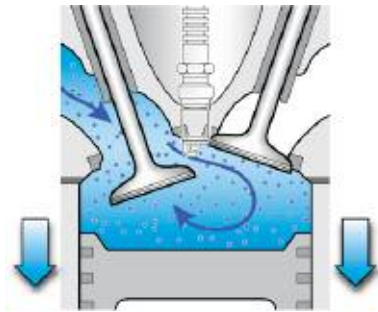
Specification	Gasoline Engine (Otto)	Diesel Engine
Ignition Type	Spark Ignition	Compression Ignition
Compression Ratio	Between 8:1 and 12:1	Between 16:1 and 22:1
Efficiency	25-30%	36-45%
Maximum Engine Speed	7000-8250 RPM	up to 5250 RPM
Exhaust Temperature (under full load)	700-1200 Degrees Celsius	300-900 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”.



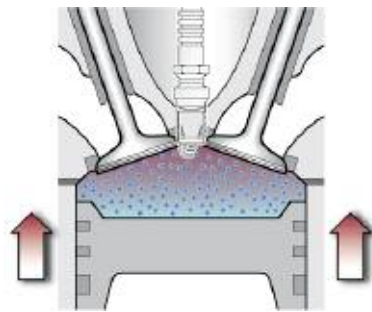
Intake Stroke Gasoline Engine

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.



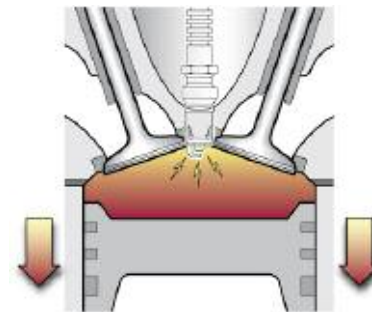
Compression Stroke Gasoline Engine

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.



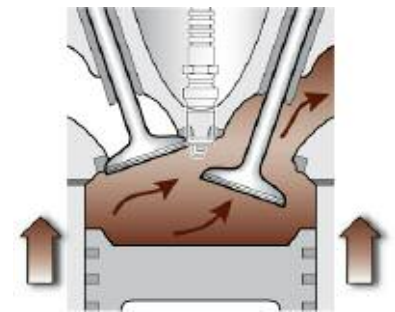
Power Stroke Gasoline Engine

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

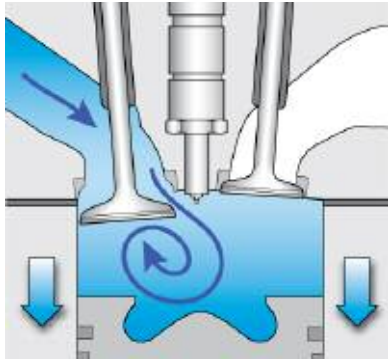
The exhaust valve opens as the piston moves up in the cylinder which expels the spent gases formed during the combustion process.

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.



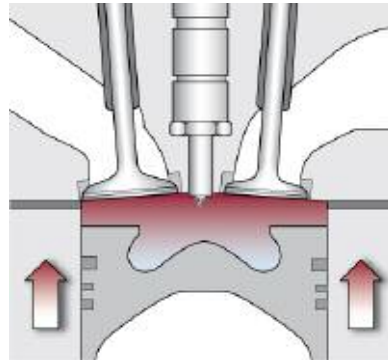
Intake Stroke Diesel Engine

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.



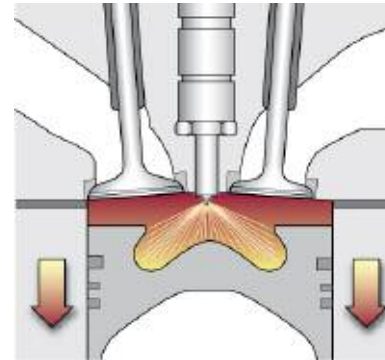
Compression Stroke Diesel Engine

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

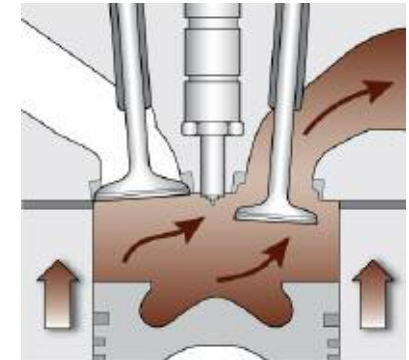
Just before the piston reaches TDC, fuel is injected at high pressure directly into the combustion chamber.

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:

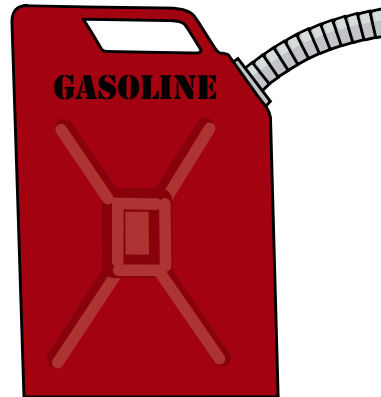
Due to the higher thermal efficiency of a diesel engine, the exhaust temperature is lower as compared to a gasoline engine.

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

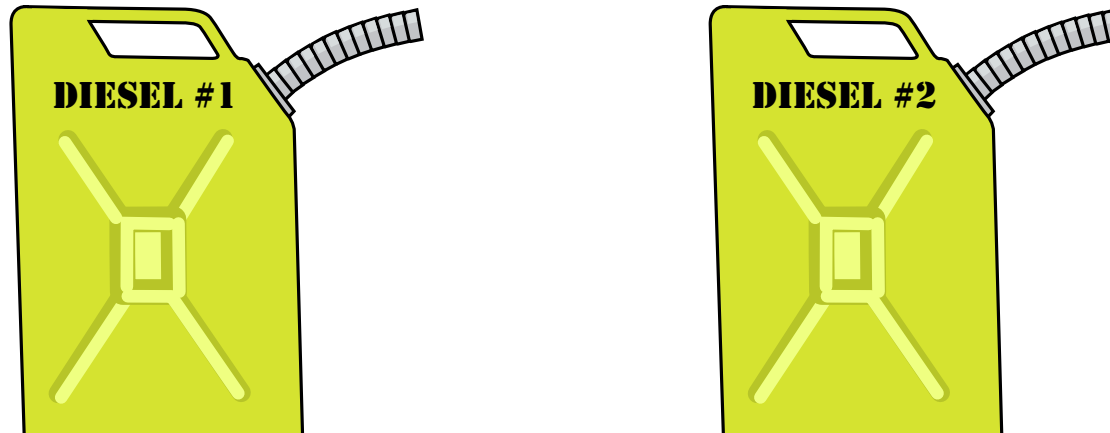
As with gasoline, diesel fuel is a by-product of the distillation of crude oil. Diesel fuel is a hydrocarbon with different chemical properties than gasoline. Diesel fuel is part of the “middle distillates” derived from crude oil. This means that diesel fuel is “heavier” than gasoline but “lighter” than 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 CO₂ per gallon. However, the increased efficiency of a diesel engine allows for an overall reduction in CO₂ (per mile). In comparison, diesel engines are run leaner (with excess air), and produce lower levels of HC, CO and CO₂. 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 at 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.

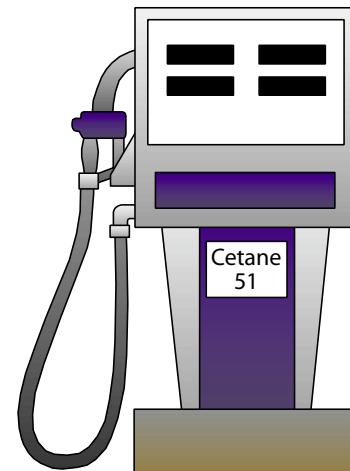
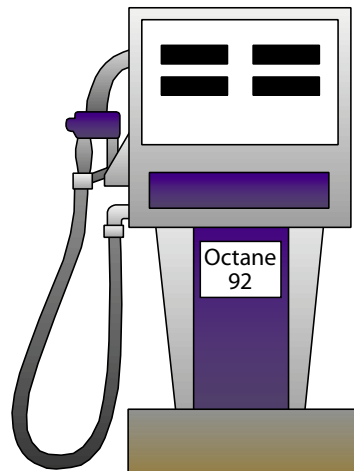
In the heavy trucking industry, there have been some other methods to “winterize” diesel fuel. Some of these methods include adding kerosene or other fuels to improve cold weather starting ability. However, this is **not** recommended for passenger cars and may, in fact, cause engine or fuel system damage.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

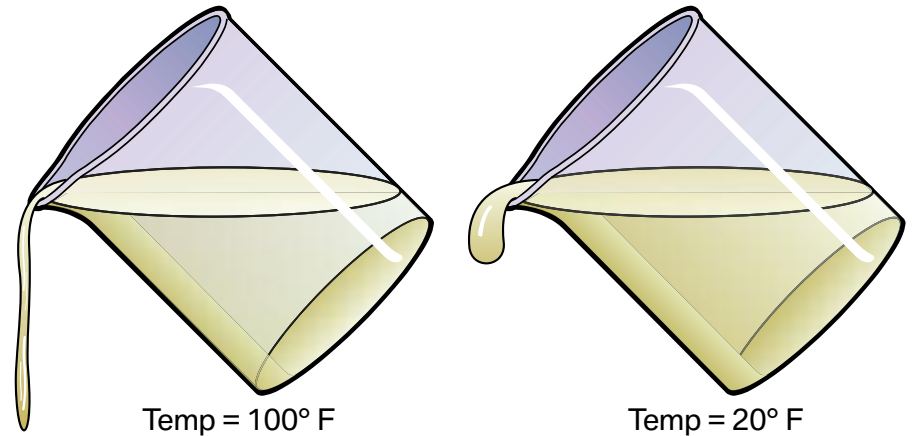


Cold Weather Properties

As with all fuels distilled from crude oil, there is a presence of paraffin wax. This wax content depends on 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.

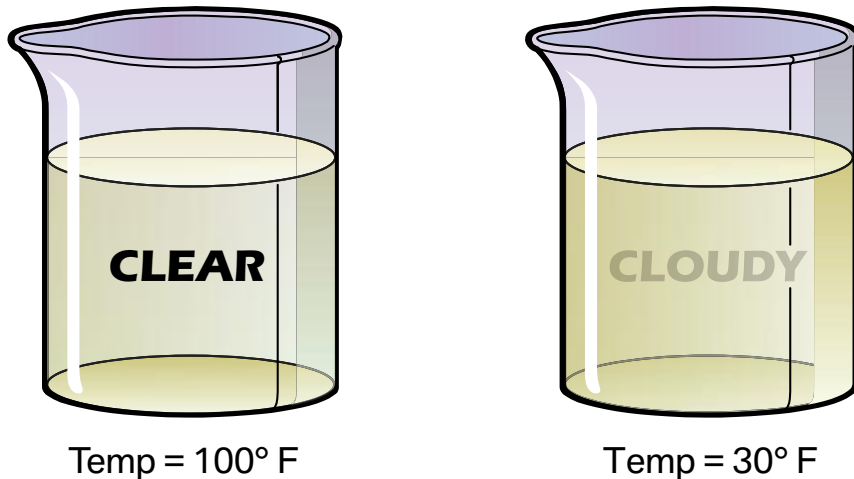
■ Cloud Point

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



Pour Point

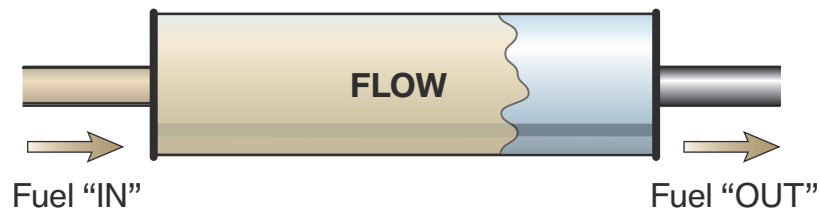
Pour point is the temperature in which the fuel will no longer flow. It is usually 6 to 10 degrees Fahrenheit below the cloud point.



fuel is about 20 degrees Fahrenheit (-7 degrees C).

■ 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.

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 in 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.

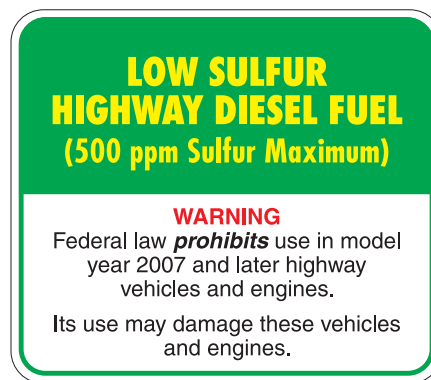
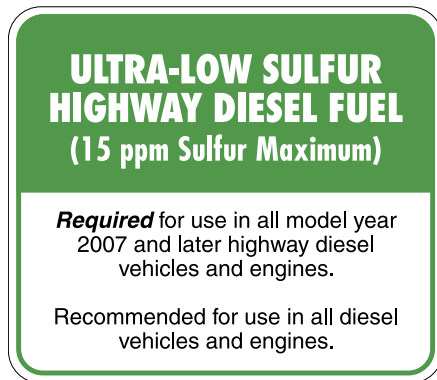
The presence of sulfur in diesel fuel contributes to unwanted soot and particulate emissions which are present in diesel exhaust. So, beginning in 1985, the EPA and CARB began with regulations on the sulfur content of diesel fuel. This led to the use of low sulfur diesel fuel.

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 reasons 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 it 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.

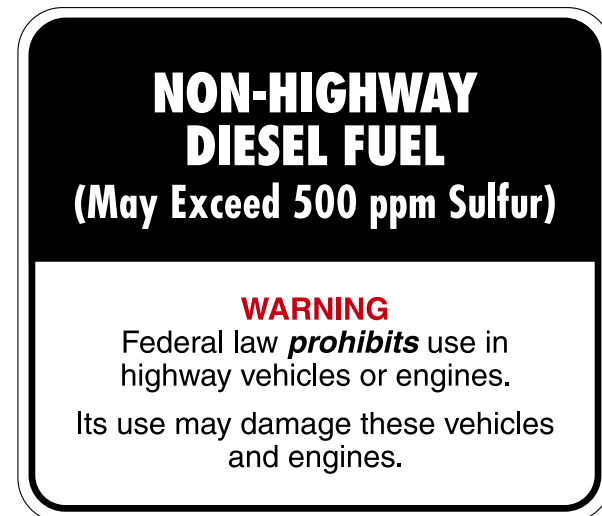
With LSD fuel and the new ULSD, additives are used to enhance the lubricity of the fuel. So, older vehicles will be able to use ULSD without any modifications or concerns.

■ 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 than diesel fuel can be ignited easier with an 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



In Diesel Engines

incorrectly with diesel fuel. Irreparable engine damage can result

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)

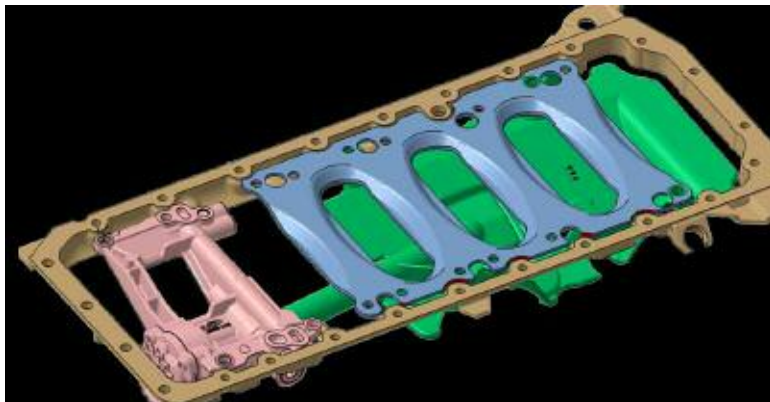
Crankcase

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.



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.

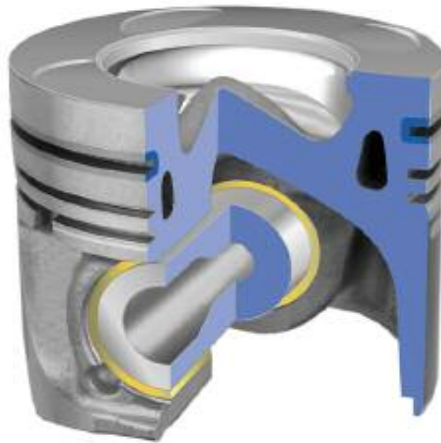
Failure to do so may result in an engine over-rev situation causing irreparable engine damage. In this case, the warranty may be affected.

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

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.

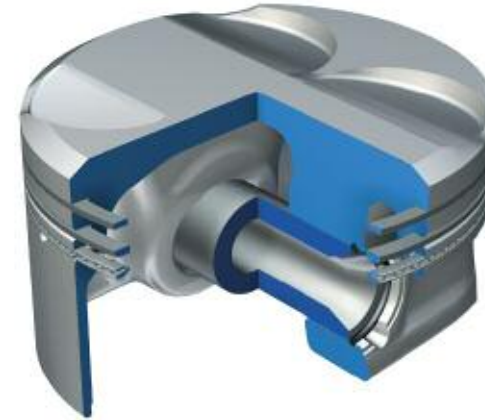
The piston crown itself is unique and features minimal valve reliefs and a large recess. This recess is used to accommodate the injector spray pattern and assist in mixture formation. The piston pin is also larger and features a bushing in the piston pin boss.

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. This 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.

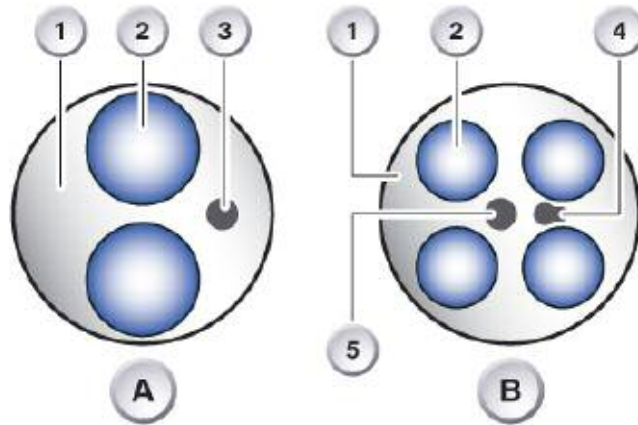


Note: Crankshaft pictured above is not a US version, due to the location of the crankshaft speed sensor wheel.

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.

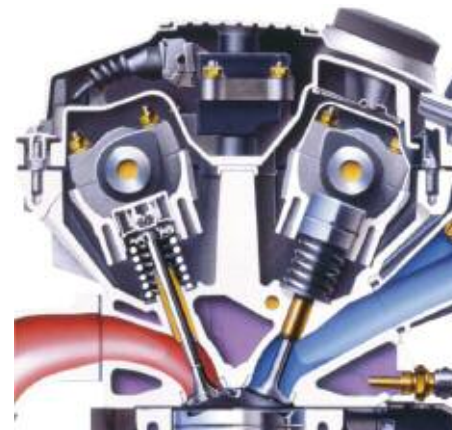
The fuel injector is also located centrally in the combustion chamber adjacent to the glow plug.



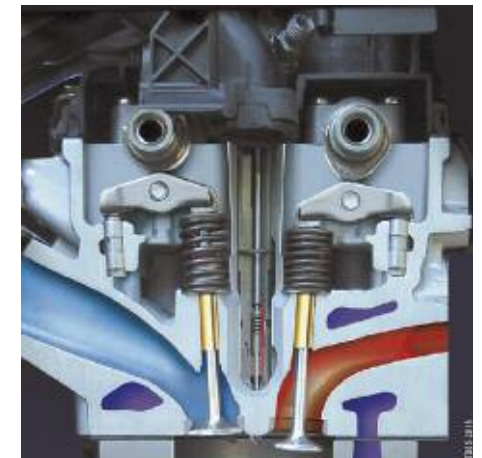
Index	Explanation
A	2-Valve arrangement (i.e. M21)
B	4-valve arrangement (i.e. M57)
1	Combustion chamber (surface/ceiling)
2	Valves
3	Injection port (swirl chamber/glow plug integrated)
4	Glow plug
5	Injector (direct injection)

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.



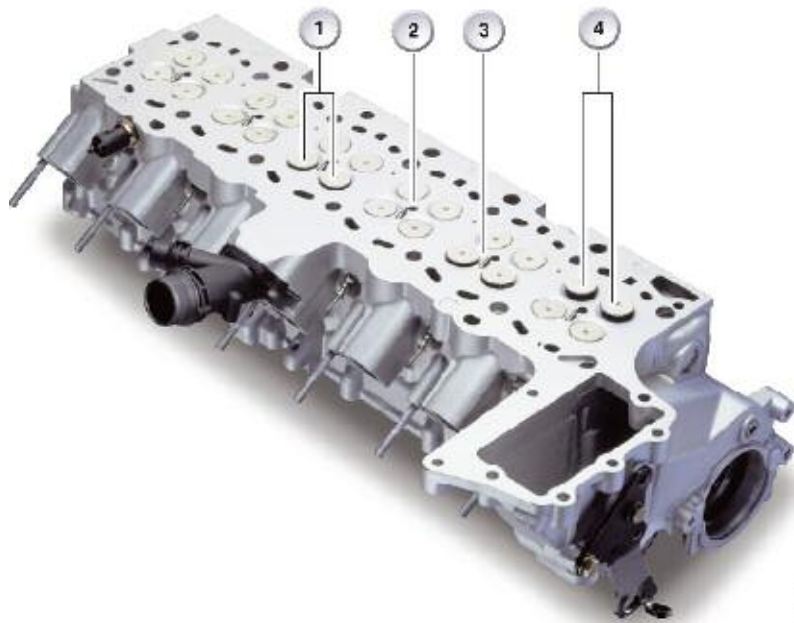
Cylinder head cross section
Gasoline Engine



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.



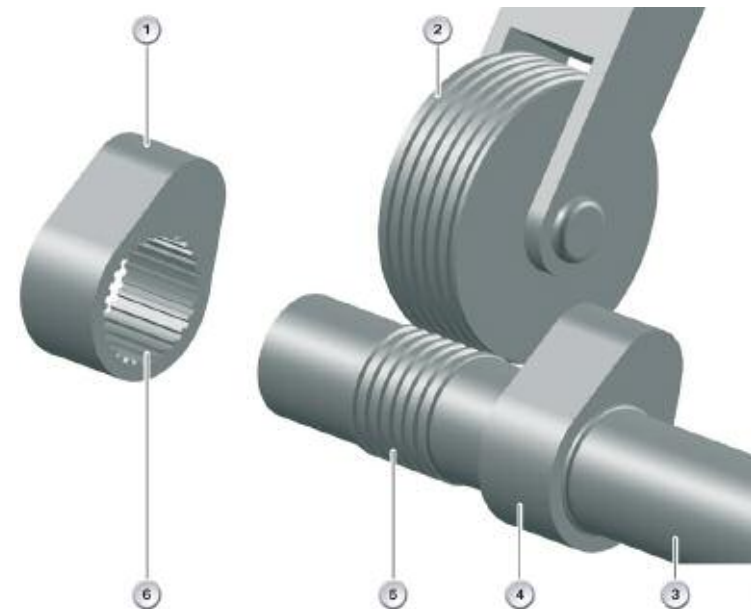
Index	Explanation
1	Intake valves (27.4 mm)
2	Injector (direct injection)
3	Glow plug
4	Exhaust valves (25.9 mm)

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.

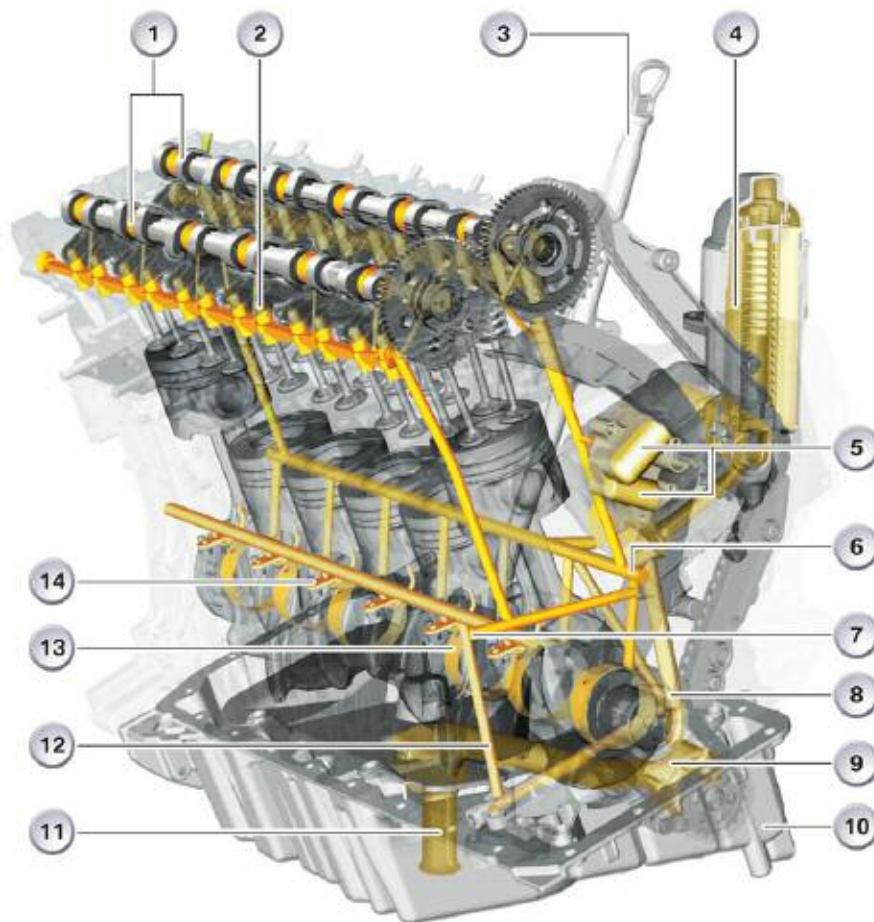


Index	Explanation
1	Camshaft lobe
2	Roller for Presta process
3	Camshaft (steel tube)
4	Camshaft lobe (locked on to steel tube)
5	“Knurling” on camshaft
6	Internal splines on camshaft lobe

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.

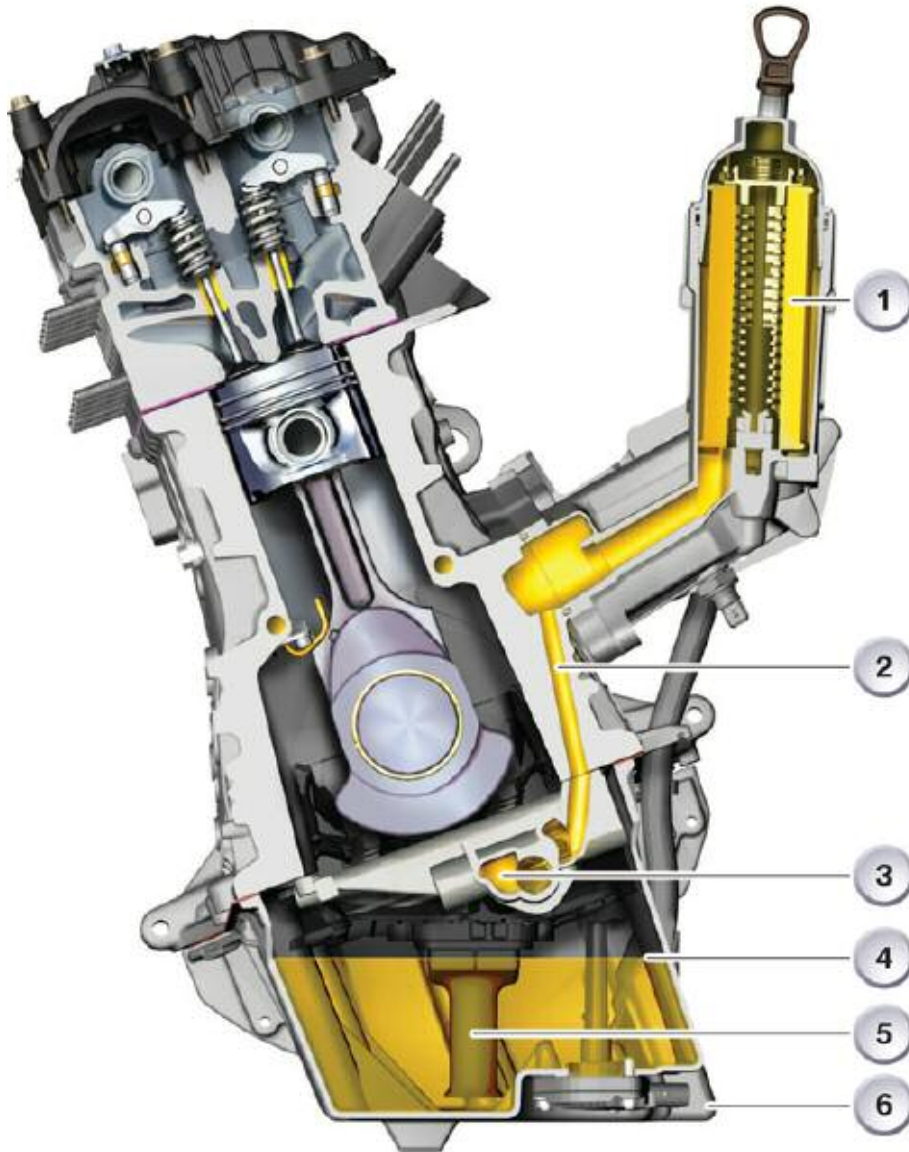
Branch galleries lead to the main bearings of the crankshaft. The crankshaft has corresponding holes to feed oil from the main bearings to the crankpins and connecting rod journals. Part of the oil is branched off from the main oil gallery and fed to the corresponding lubrication points in the cylinder 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

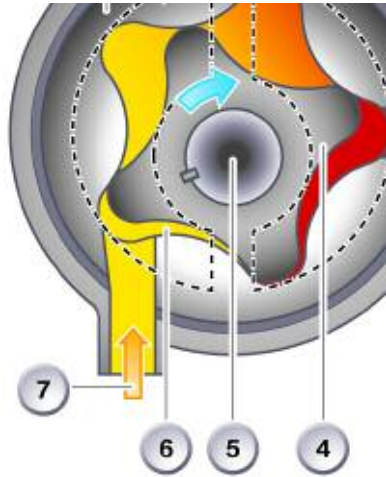
The oil pump (3) draws in oil from the oil pan (6) via the intake pipe with oil screen (5). The intake pipe is positioned such that the intake opening is above the oil level (4) under all operating conditions. An oil screen is integrated in the intake pipe in order to keep coarse dirt particles away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

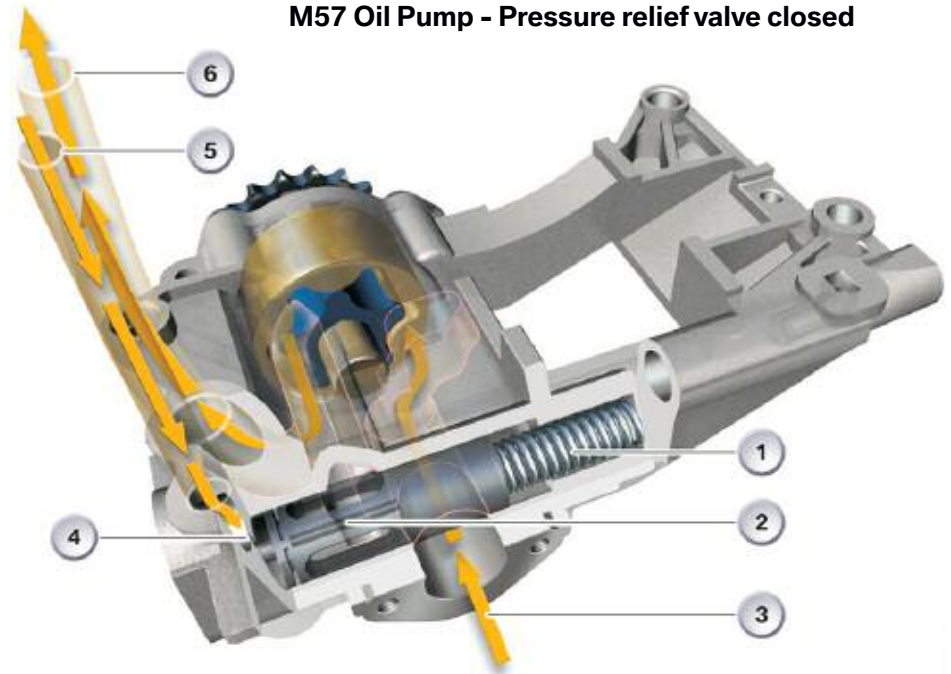
Functional Principle

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.

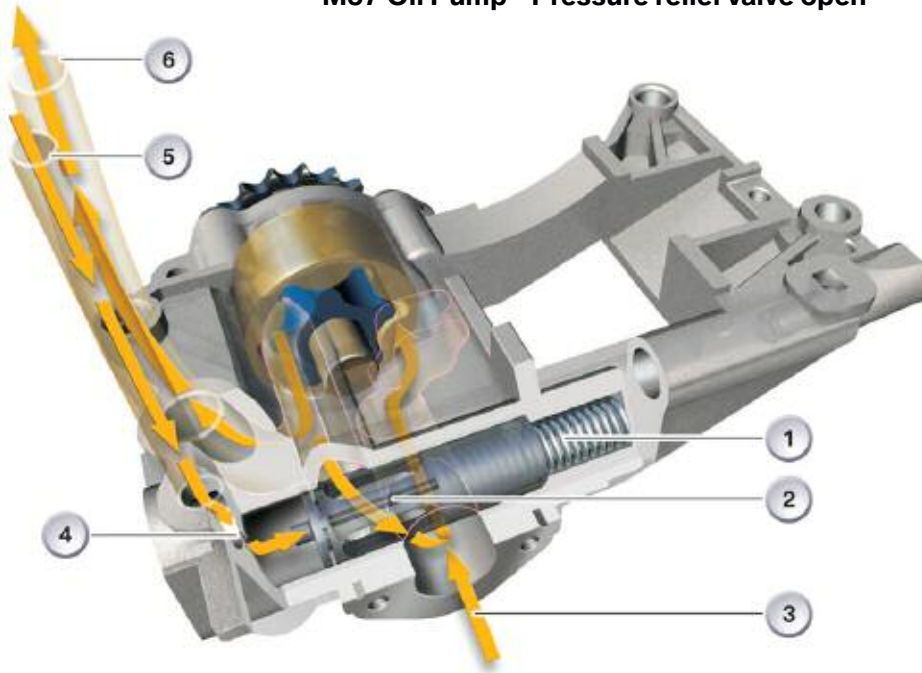
M57 Oil Pump - Pressure relief valve closed



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.

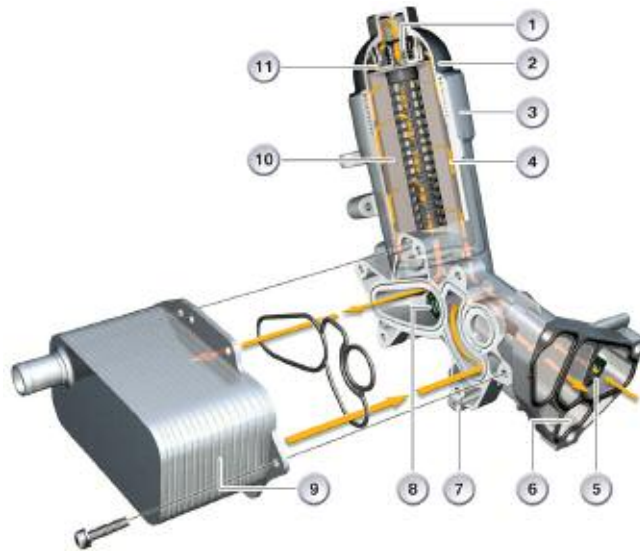
The opening and control pressure depends on the respective type of engine and is between 3 bar and 5. Specifically, the control pressure on the M57TU2 is 4.0 bar.

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 over-pressure of 2.5 bar and the oil will flow (unfiltered) to the lubrication points.

■ Heat Exchanger Bypass Valve

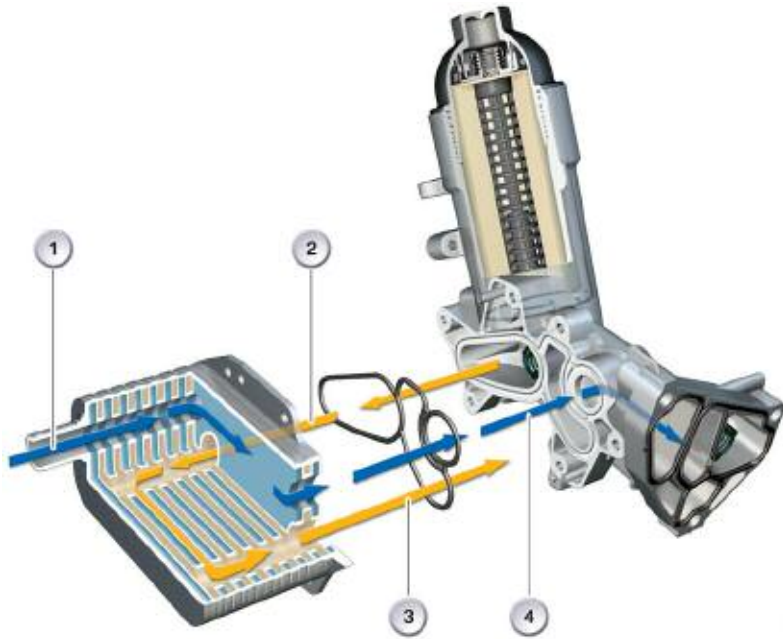
The heat exchanger bypass valve (8) has the same function as the filter bypass valve (1). If the oil pressure increases because the oil-to-coolant heat exchanger (9) is clogged, the heat exchanger bypass valve (8) will open at a pressure of 2.3 bar, allowing the

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 loses 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.

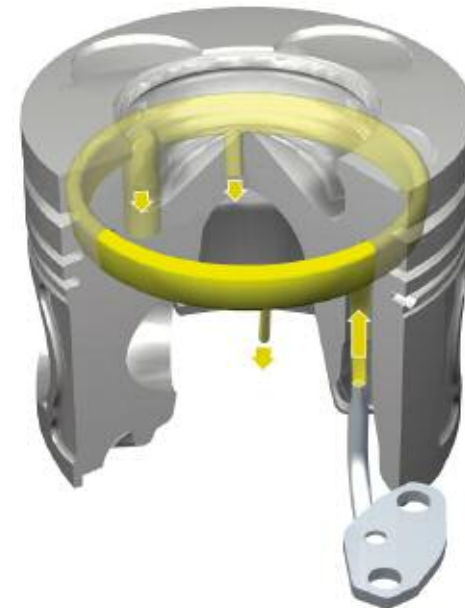
The oil flows through the engine oil cooler with its large surface area facilitating effective heat dissipation.

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, NO_x 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.

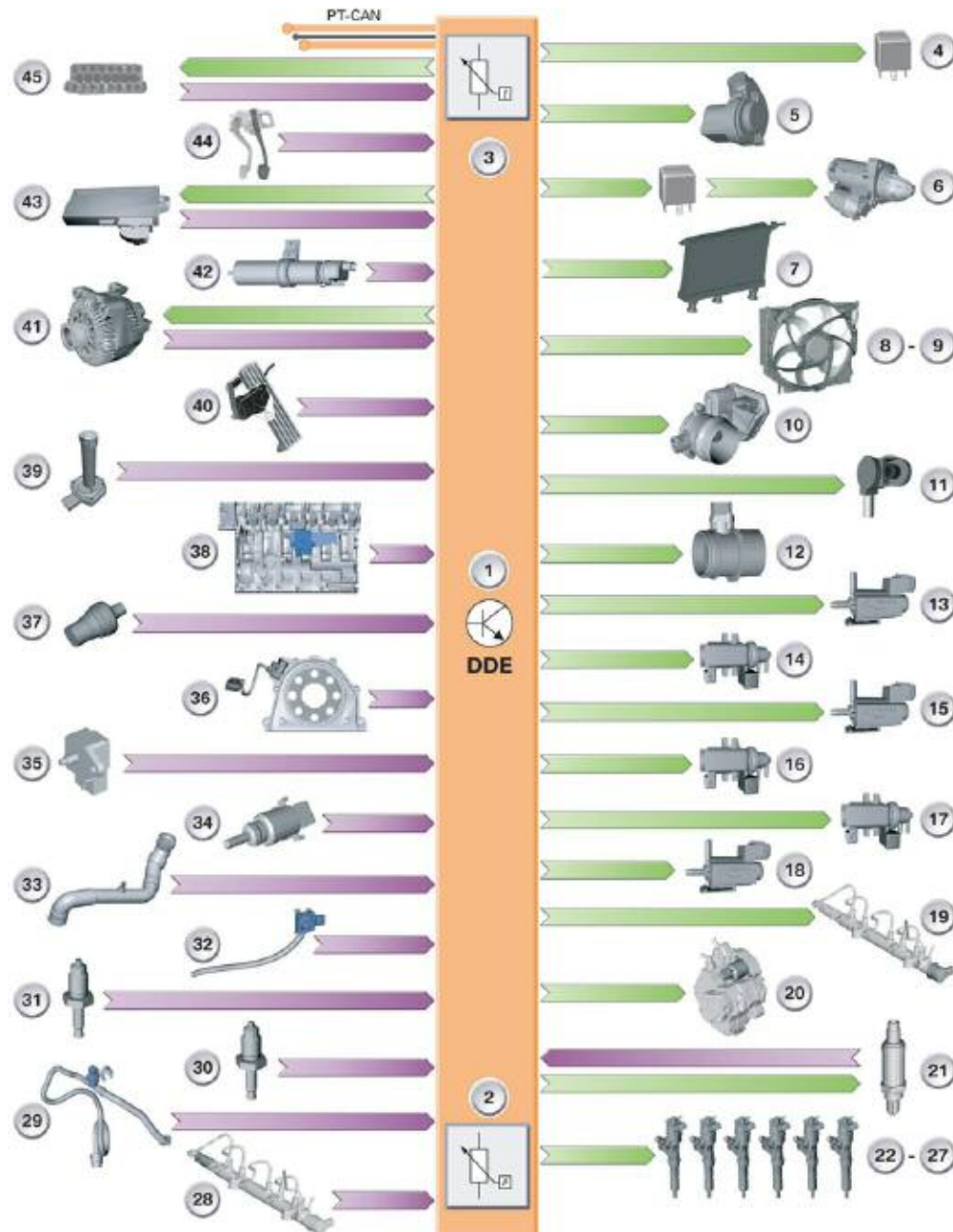
The ambient pressure sensor makes it possible for the density of the ambient air to be precisely determined - a variable that is used in numerous diagnostic functions. Furthermore, it is needed if the cylinder charge is being calculated from the substitute variables in the event of a hot-film air mass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

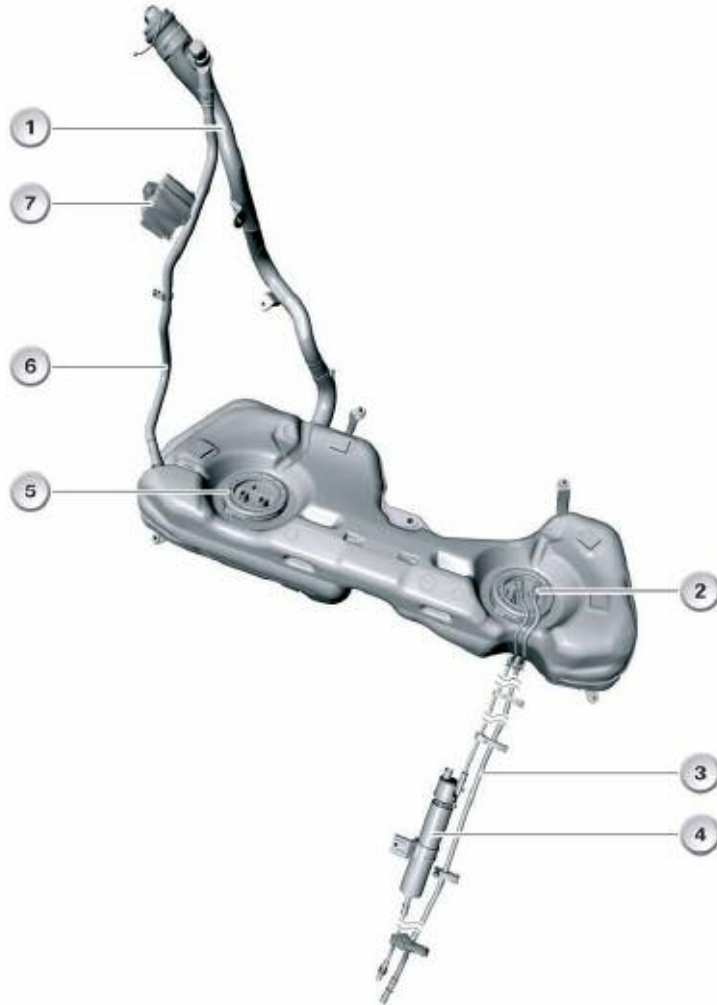
Vacuum controlled via electric changeover valve (on/off)

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.

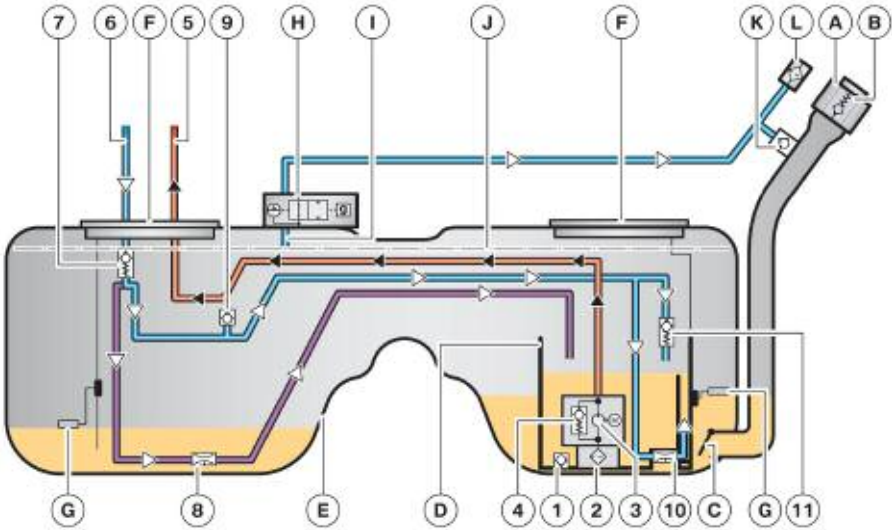
So, the fuel tanks in the diesel vehicles feature the familiar “double-chamber” configuration. This design feature accommodates two delivery units which are located in the right and left fuel tank halves.

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.

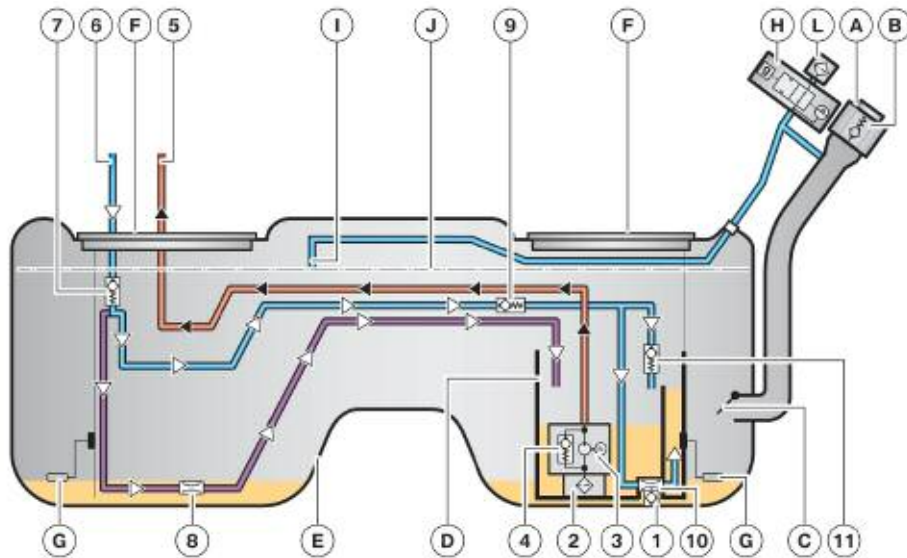
A line leads from the filler vent valve (H) to the filter (L). The fuel filler pipe is connected to this line via the non-return valve (K).

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

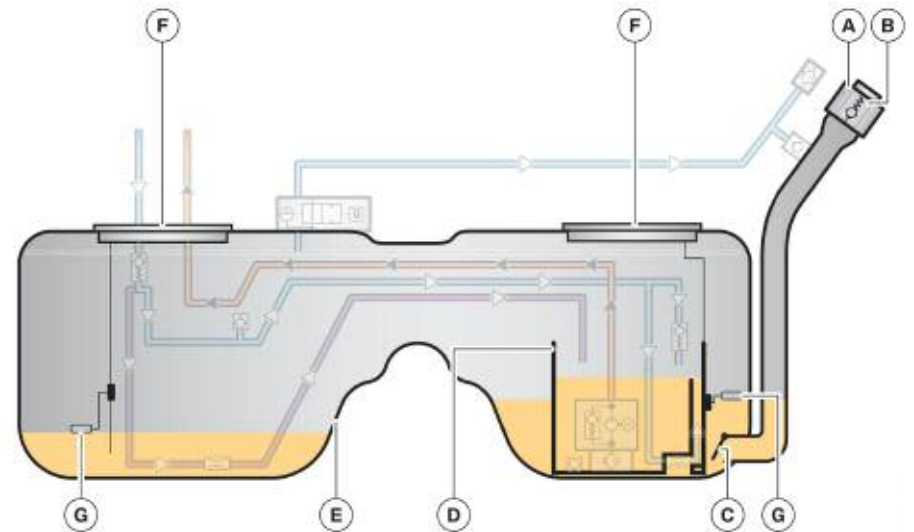


Index	Explanation	Index	Explanation
A	Fuel filler cap	1	Initial fill valve
B	Pressure relief valve	2	Intake mesh filter
C	Non-return valve	3	Fuel pump
D	Surge chamber	4	Pressure relief valve
E	Fuel tank	5	Feed line
F	Service cap	6	Return line
G	Lever-type sensor	7	Leak prevention valve
H	Filler vent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

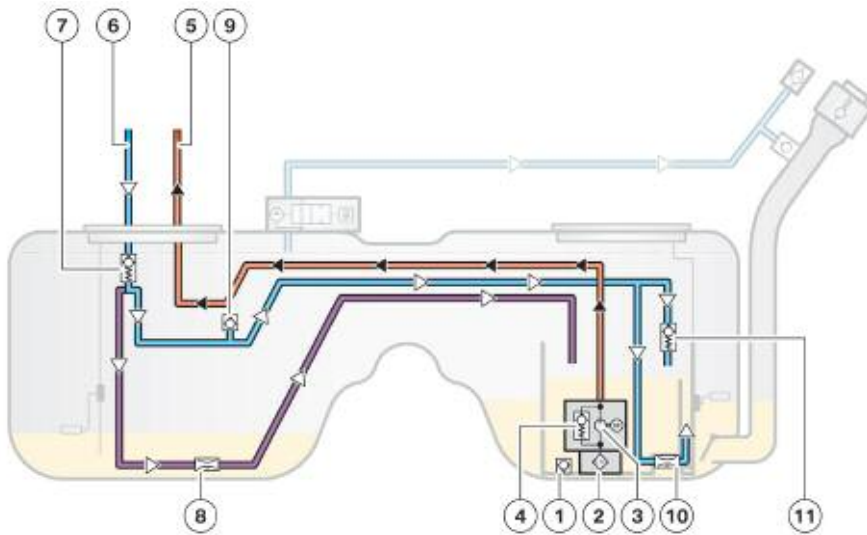


Index	Explanation	Index	Explanation
A	Fuel filler cap	E	Fuel tank
B	Pressure relief valve	F	Service cap
C	Non-return valve	G	Lever-type sensors
D	Surge chamber		

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).

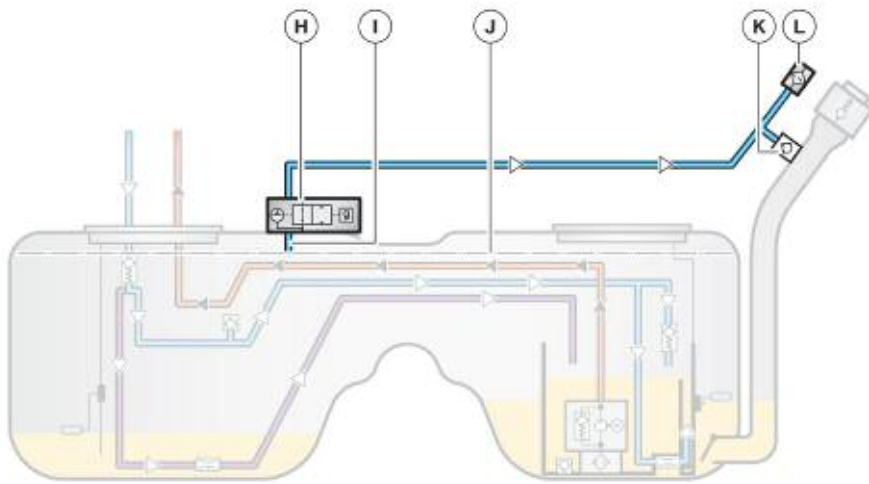
Air Supply and Extraction

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.

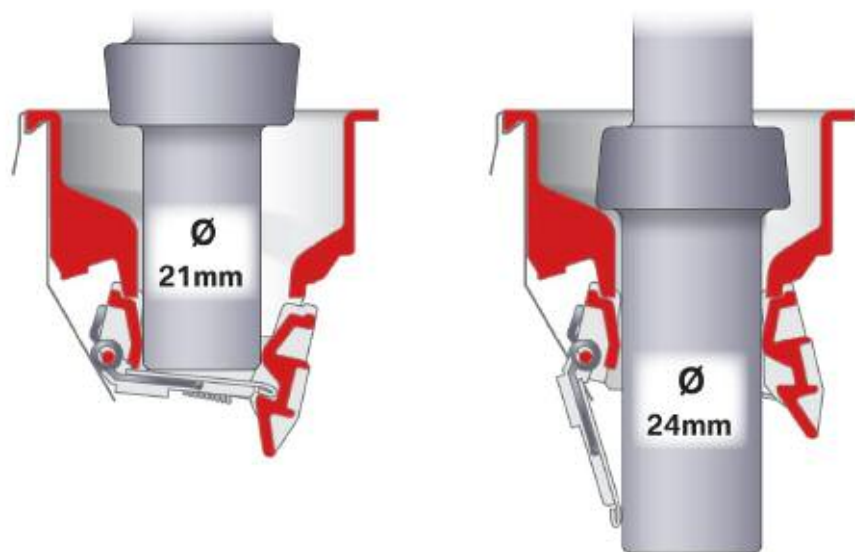
The excess pressure spring uses a defined pressure to push the pressure relief valve onto the sealed housing and is supported by the brace (3).



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

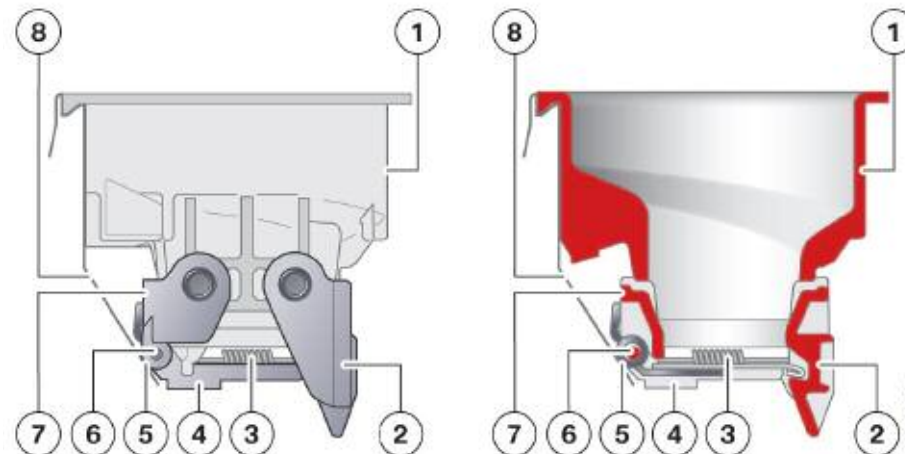
A mechanical system has been developed in order to help prevent a mis-fueling situation. To make sure that the diesel vehicles are only refueled with the proper diesel fuel, a mechanical flap has been added to the fuel filler neck.



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.

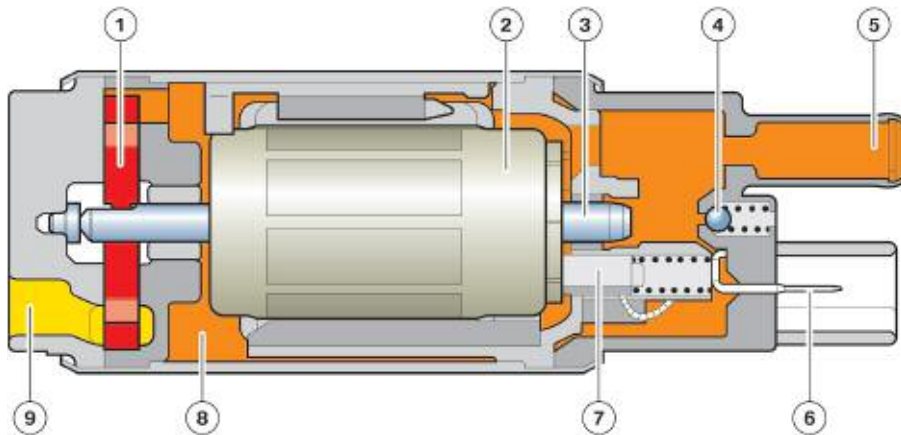


Index	Explanation	Index	Explanation
1	Housing	5	Torsion spring
2	Locking lever	6	Rivet
3	Tension spring	7	Hinged lever
4	Flap	8	Ground strap

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.

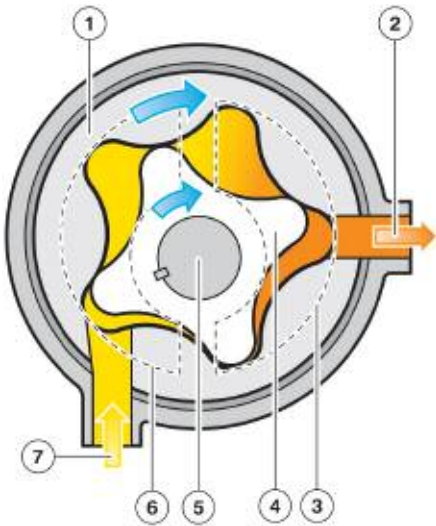
If the fuel delivery pressure increases to an impermissible value, the pressure relief valve (4) opens and allows the fuel to flow into the surge chamber.

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).

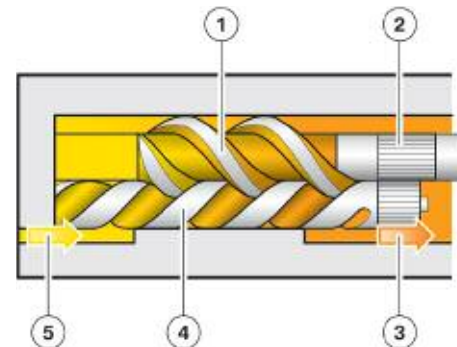


Index	Explanation
1	Outer rotor
2	Fuel delivery to engine
3	Pressure section
4	Inner rotor
5	Driveshaft
6	Intake section
7	Fuel from tank

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.

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 temperature sensor - E90



■ 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:

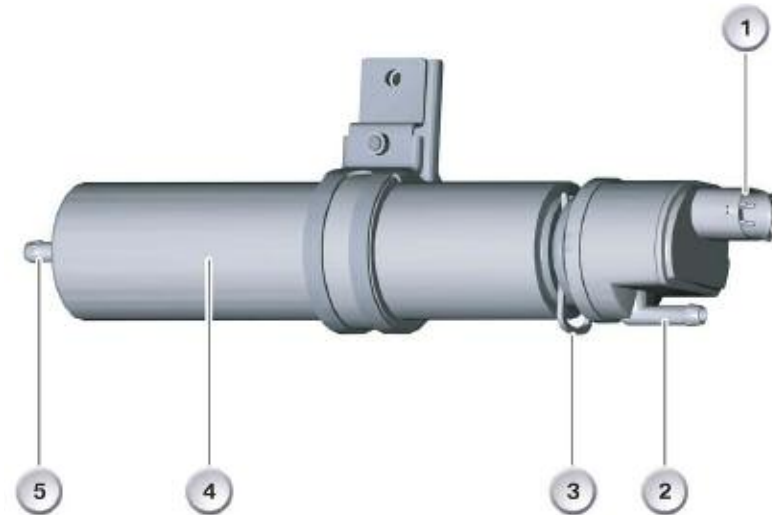
- Temperature drops below a defined value
- A defined fuel delivery pressure is exceeded due to cold, viscous fuel.

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:

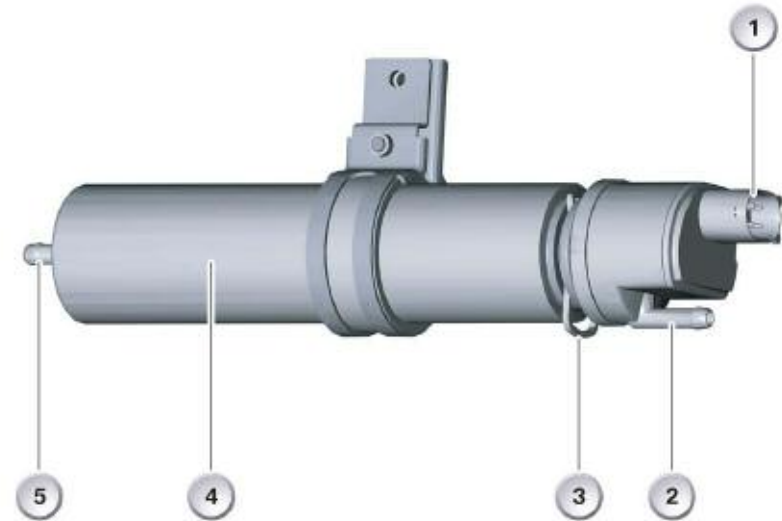
- Temperature drops below a defined value
- The required fuel pressure is not reached despite increased power intake of the electric fuel pump.

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:

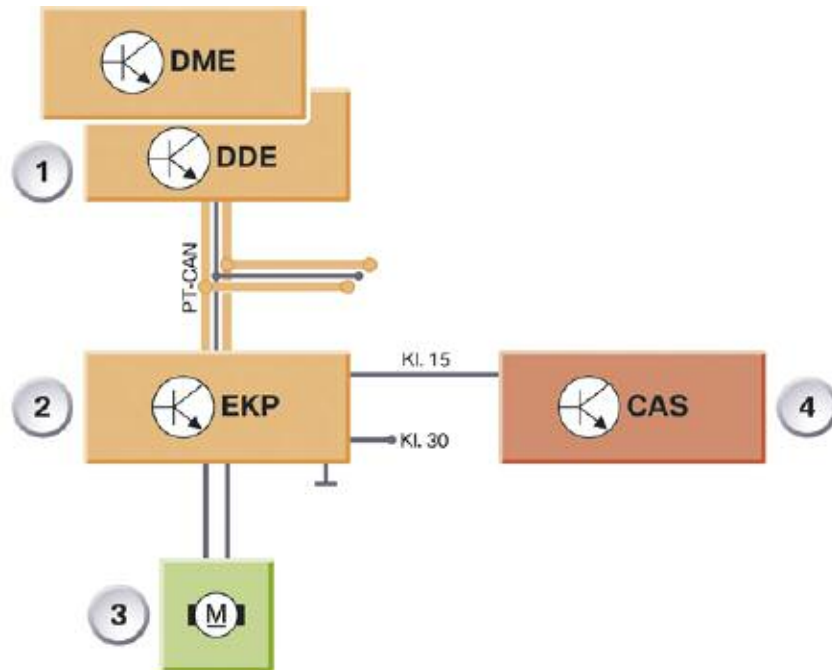
- Activation time > 5 min or
- Fuel temperature > 8°C or
- Battery voltage is less than 9 volts for more than 30 seconds



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).

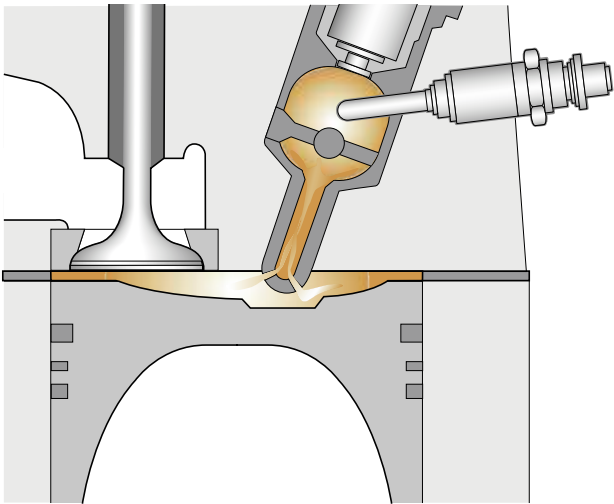
The number of waves produced per revolution is equal to the number of existing commutator segments.

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.

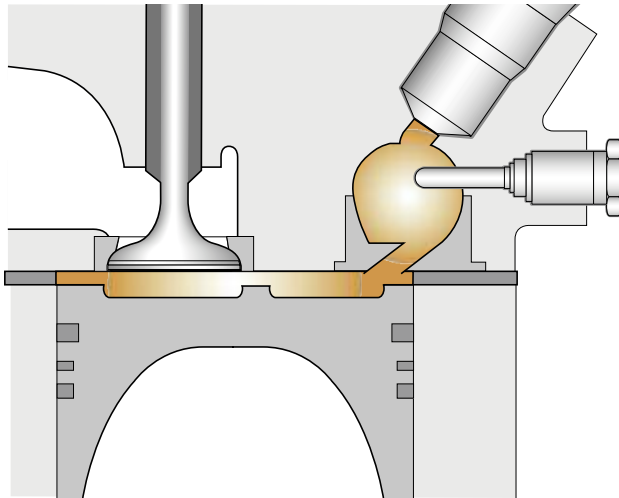
High Pressure Fuel Systems

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.

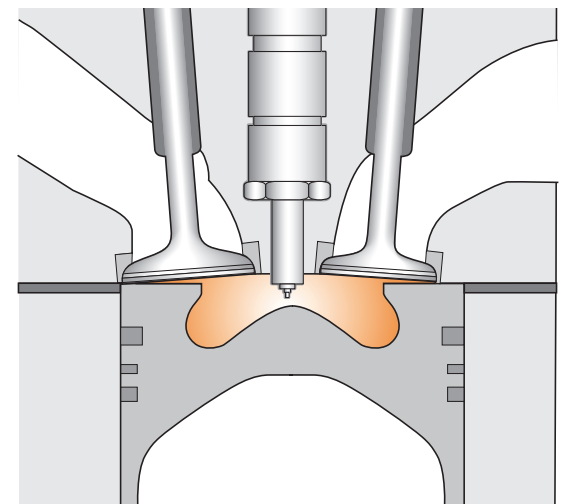
Indirect injection (IDI) can be broken down further into two groups. The “pre-chamber” design and the “swirl” (or turbulence) chamber design. As far as BMW current BMW diesel vehicles are concerned, the direct injection arrangement on the diesel is only used with common rail injection systems. Common 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.

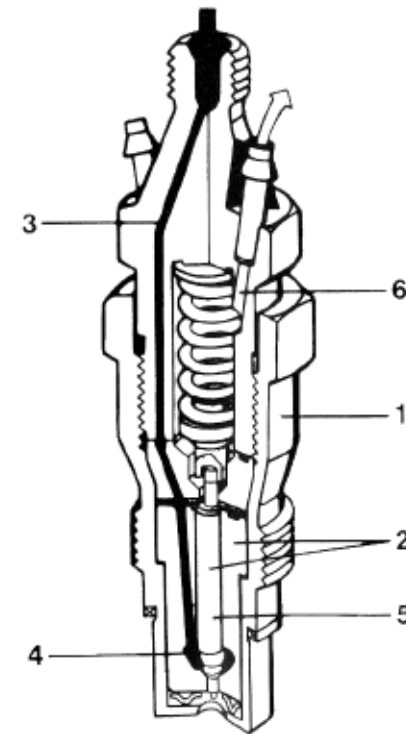
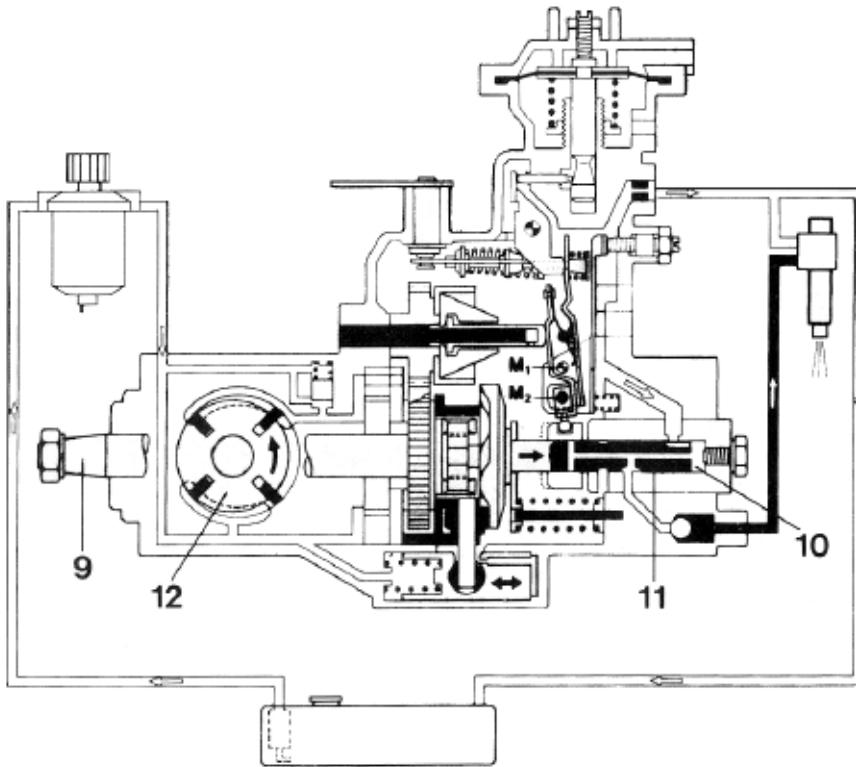
Now, with Digital Diesel Electronics (DDE) from BMW, the latest common rail systems are capable of providing multiple injection events. There is now the possibility of “pre” and “post” injection events. The pre-injection phase allows for a significant reduction in engine noise as compared to the earlier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

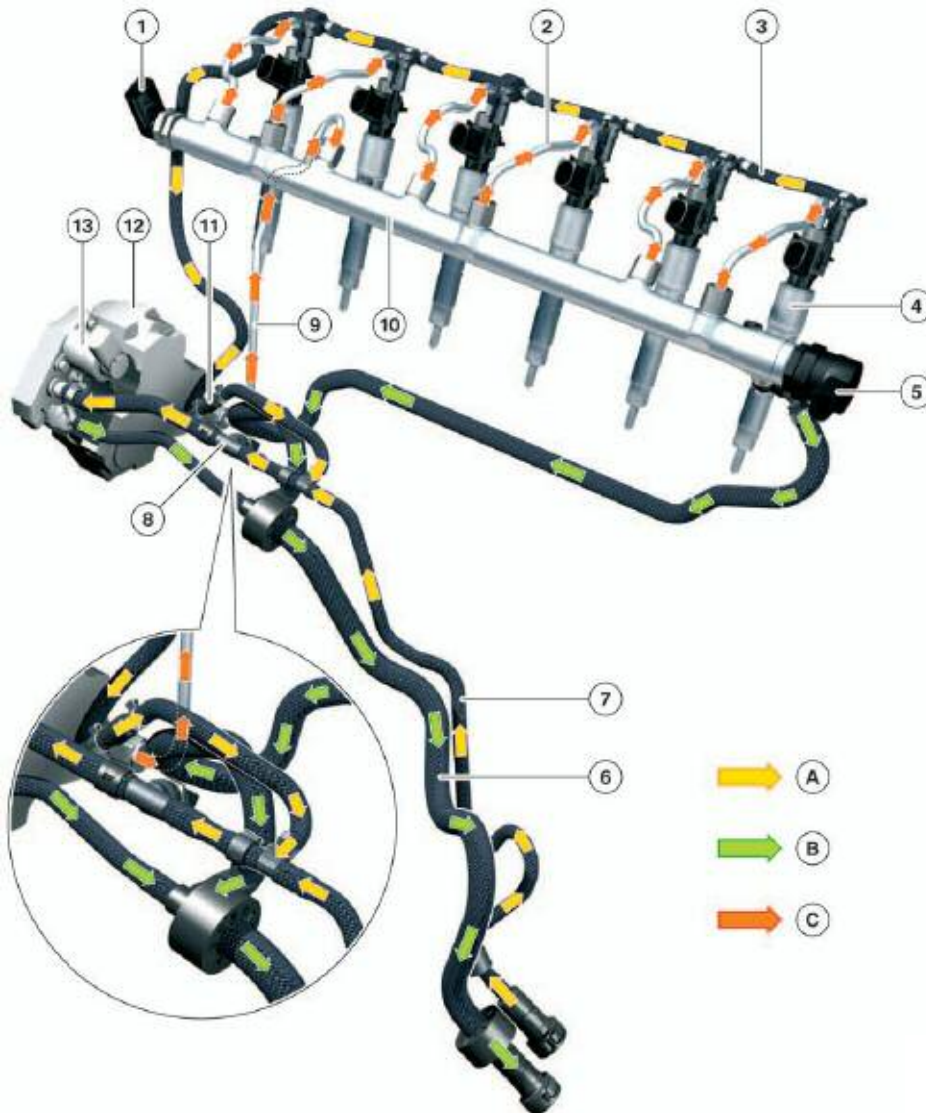
The use of electronically controlled fuel injectors allows for more precise control over exhaust emissions and noise characteristics. The engine noise or “clatter” which is usually associated with diesel engines is greatly reduced by the modern common rail injection system.

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

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

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

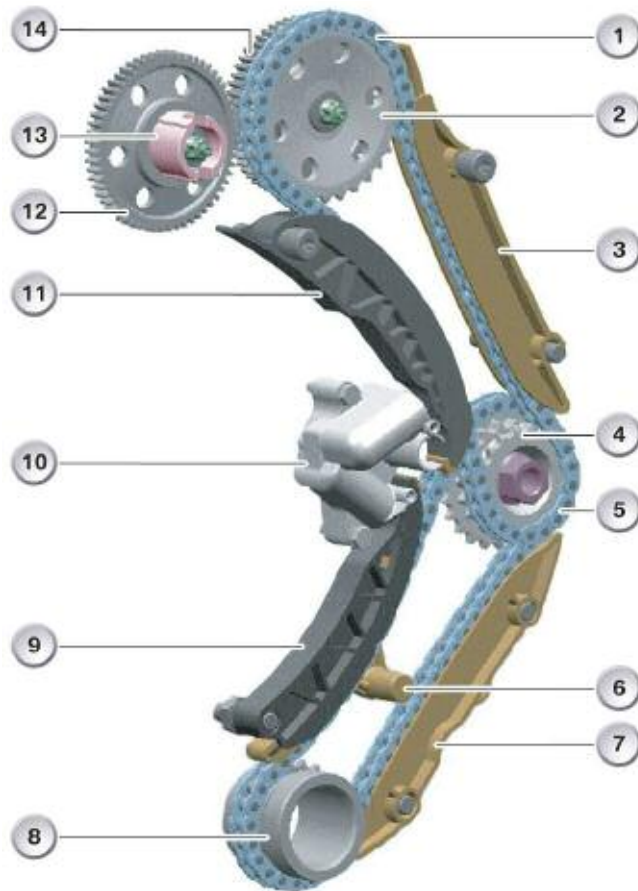
These adaptations are restricted to different coatings and materials on the inside.

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 mm³, 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.

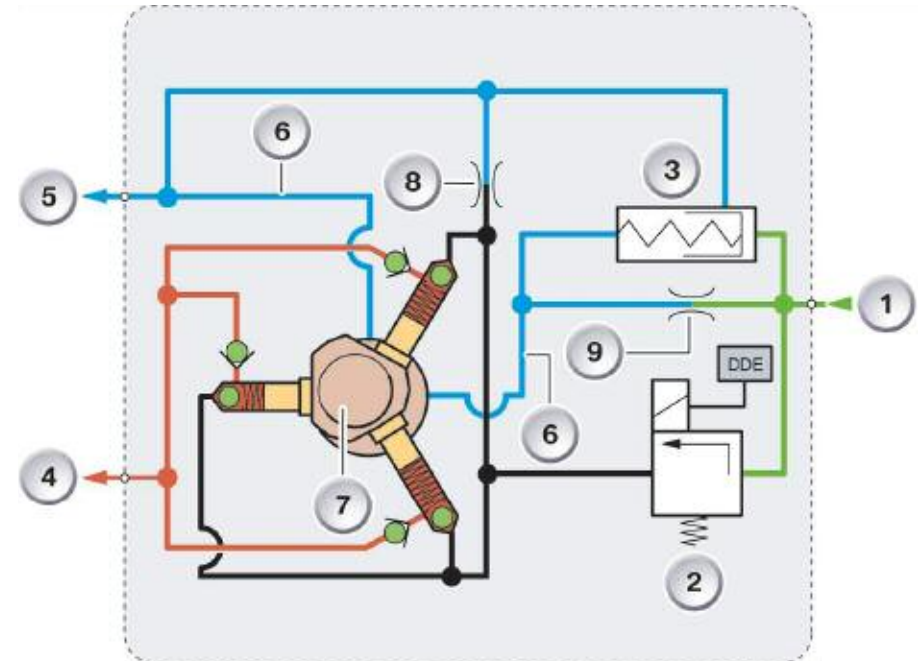
Each cylinder of the high pressure pump features ball valves for fuel inlet and outlet. The volume of fuel calculated by the DDE flows via the volume control valve (2) into the cylinders of the high pressure pump.

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 3rd 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).

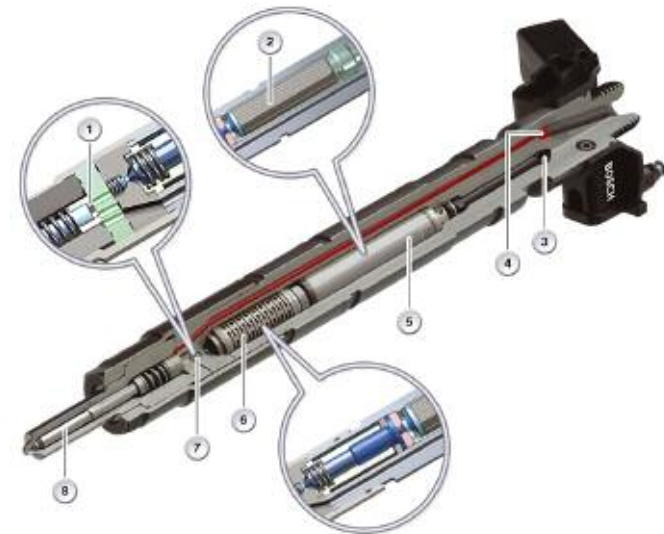
Instead, the piezo element is used to trigger a relay valve in the actuator module. The injector is then hydraulically “imbalanced” which causes the pintle to open via the fuel rail pressure.

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.

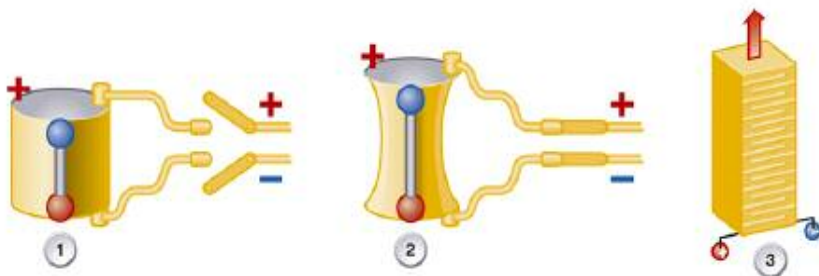
The new fuel injector design uses a piezo-ceramic elements and an electro-mechanical converter. This “inverse piezoelectric effect” is now used to convert electrical signals into mechanical movement.

Piezo Technology

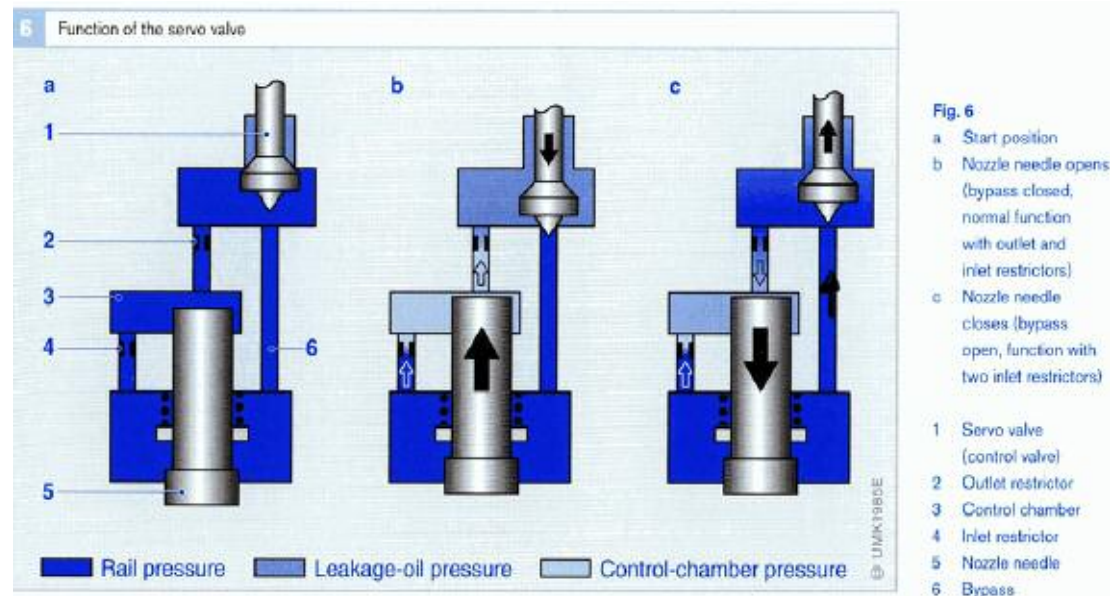
Some of the first discoveries in piezoelectric technology were as early as the 1880's. Among the early pioneers in this area was Pierre and Jacques Curie. It was discovered that certain naturally occurring crystals (such as quartz and topaz) exhibited surface charges when subjected to external forces.

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



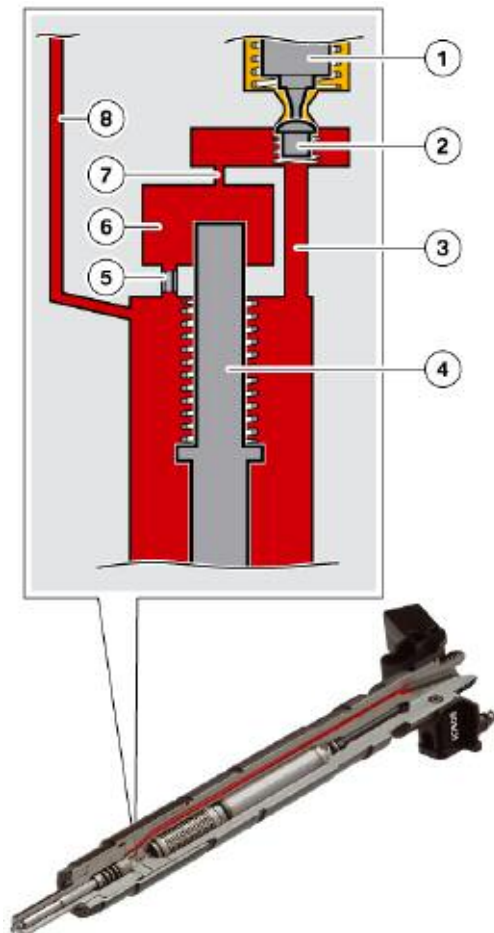
Fuel Injector Operation

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.

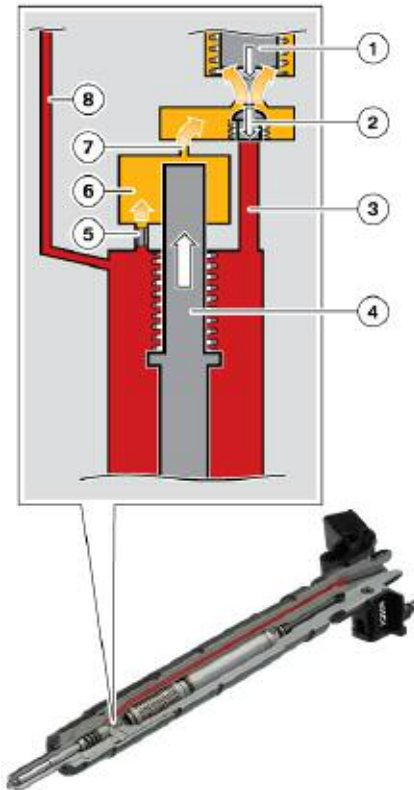
The benefits of the PIEZO injector are that they offer a considerably faster control response, which results in greater metering accuracy.

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

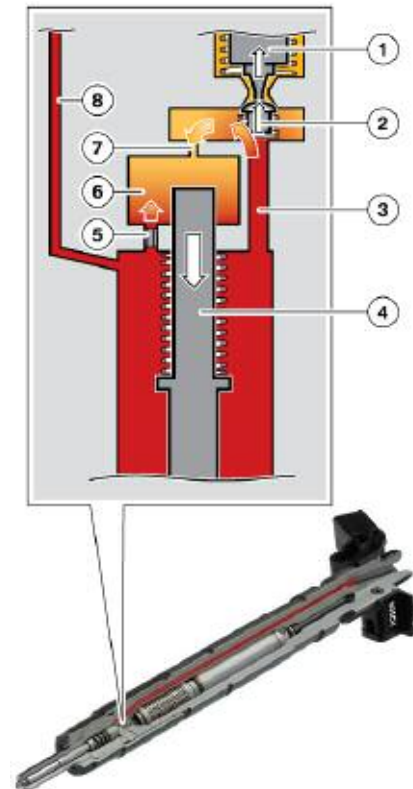
Piezo Injector Operation



■ 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.

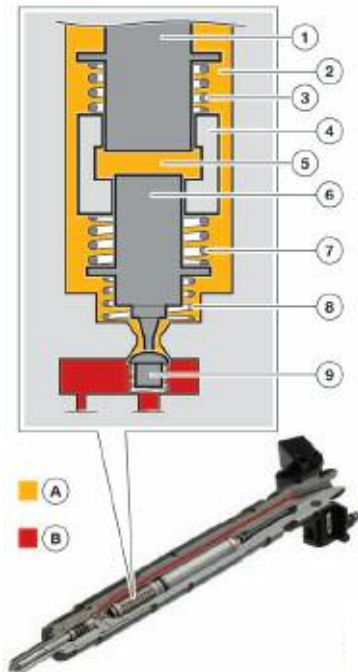
■ Coupler Module

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

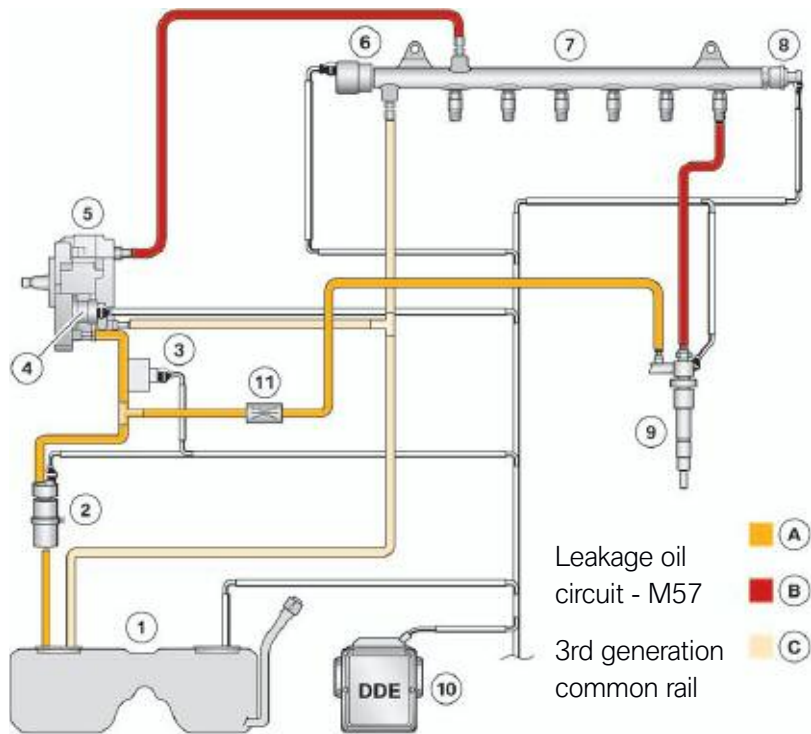
The piezo injectors require a certain amount of backpressure in the leakage circuit in order to operate properly. So, the leakage circuit on the 3rd generation common rail differs from the earlier versions.

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.

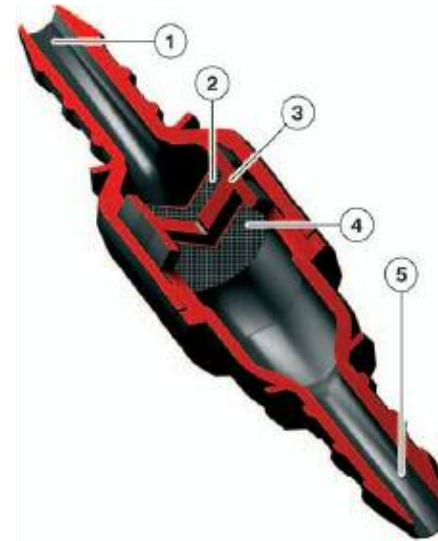
In order to maintain this pressure, a restrictor (11) has been installed between the injector(s) and the low pressure feed to the HP pump.



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 1 mm^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 (λ 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 λ 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 λ 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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Diesel Air Management

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.

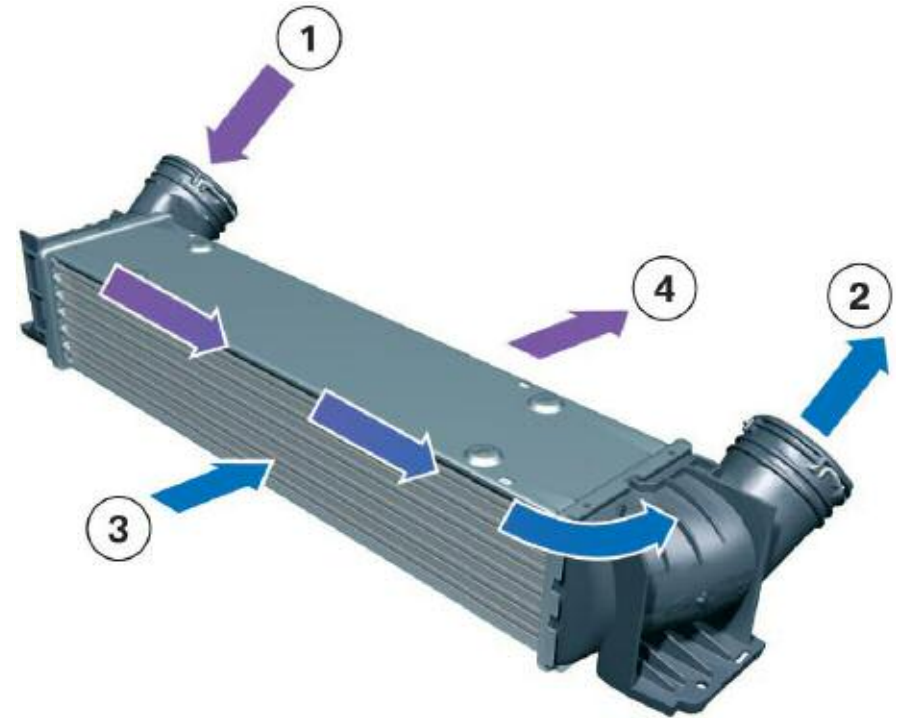
On BMW diesel engines, charge air is cooled exclusively by fresh air with an air-to-air heat exchanger. The charge air cooling rate greatly depends on the vehicle speed, temperature of the incoming fresh air and the design of the intercooler.

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.

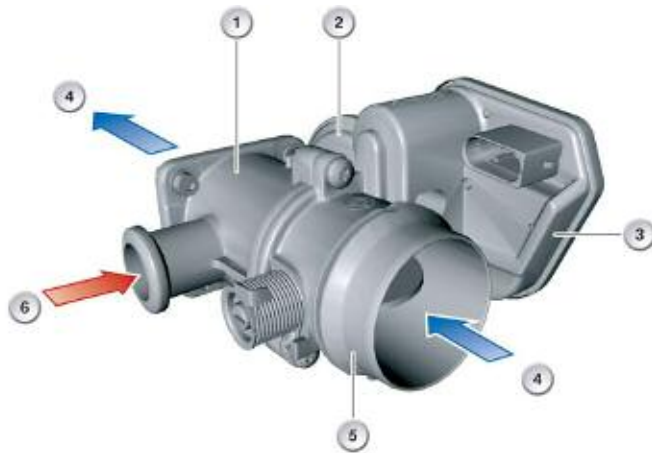
As a result, a larger volume of fuel-air mixture can be combusted and converted into mechanical energy. The intercooler is responsible for reduced intake air temperatures compared to a vehicle with no intercooler. This means the power output can be additionally increased as a larger mass of air can be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

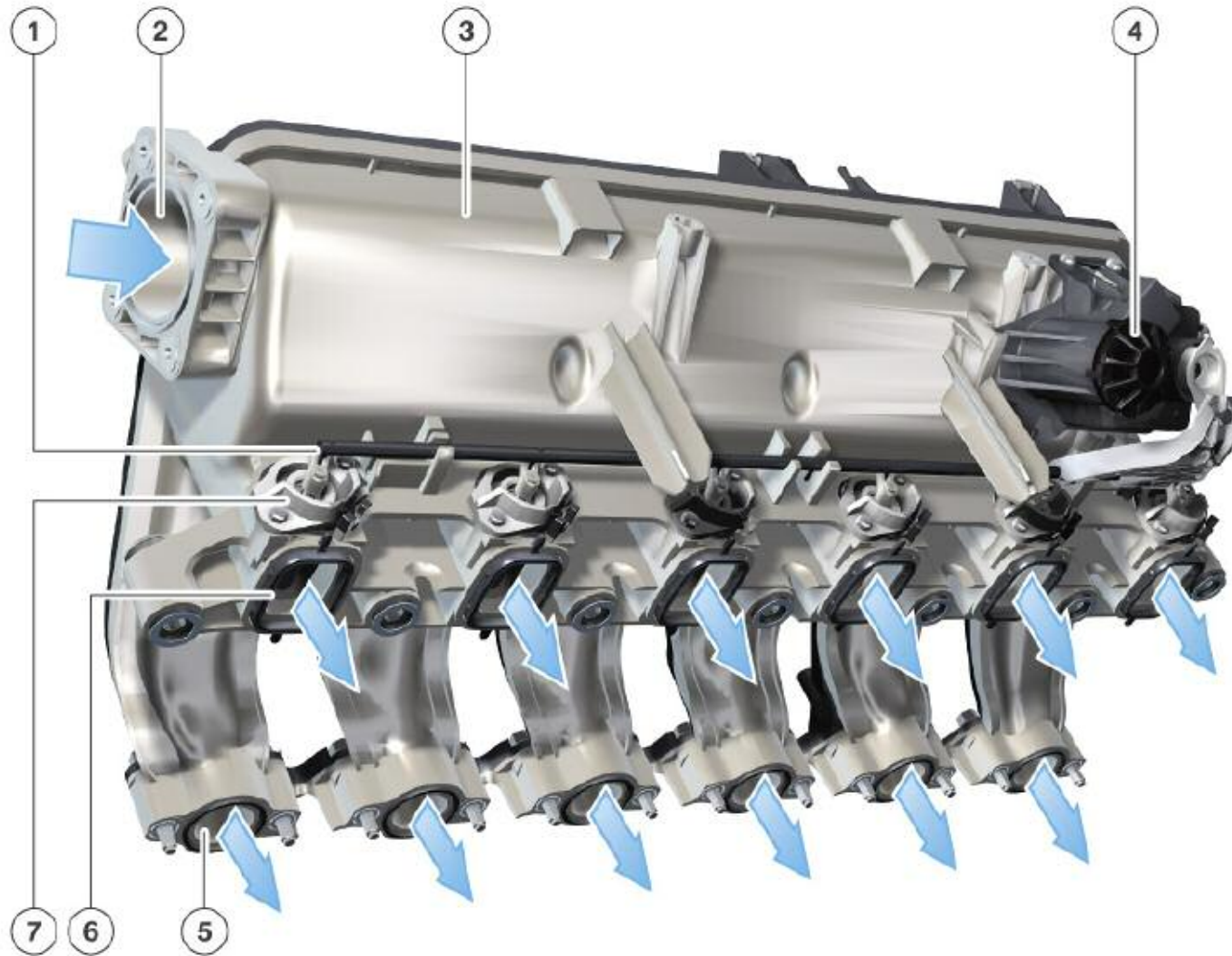
The position is based on the driver's load choice, engine speed and the coolant temperature.

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.

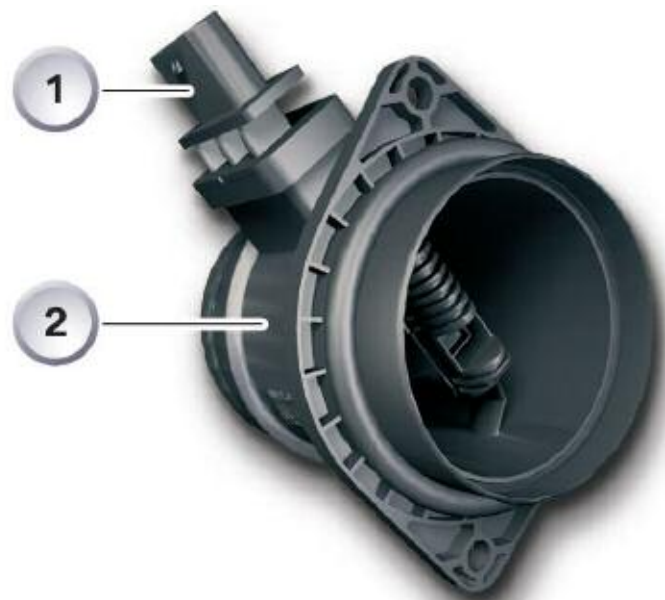


Index	Explanation	Index	Explanation
1	Control rod for swirl flaps	5	Swirl ports
2	Throttle plate mounting	6	Tangential ports
3	Intake manifold	7	Swirl flaps
4	Electric motor (for swirl flaps)		

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.

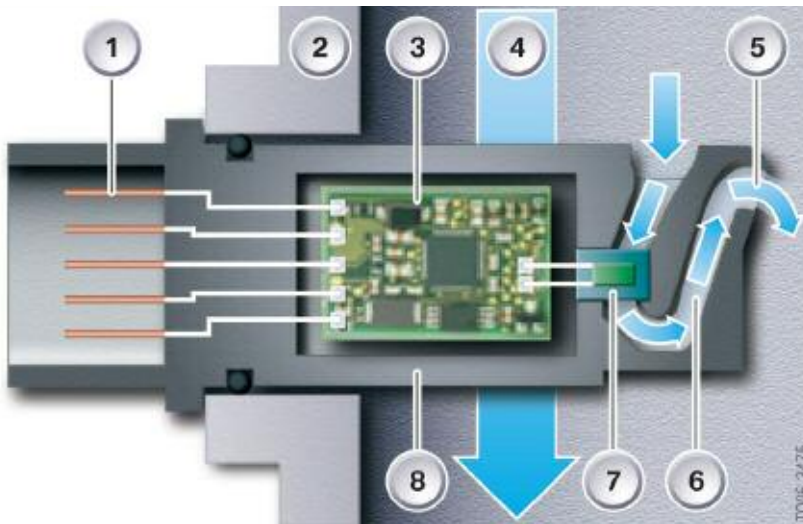
A pulse width of 22% equates to a temperature of -20°C and a pulse width of 63% equates to a temperature of 80°C.

■ Measurement Method

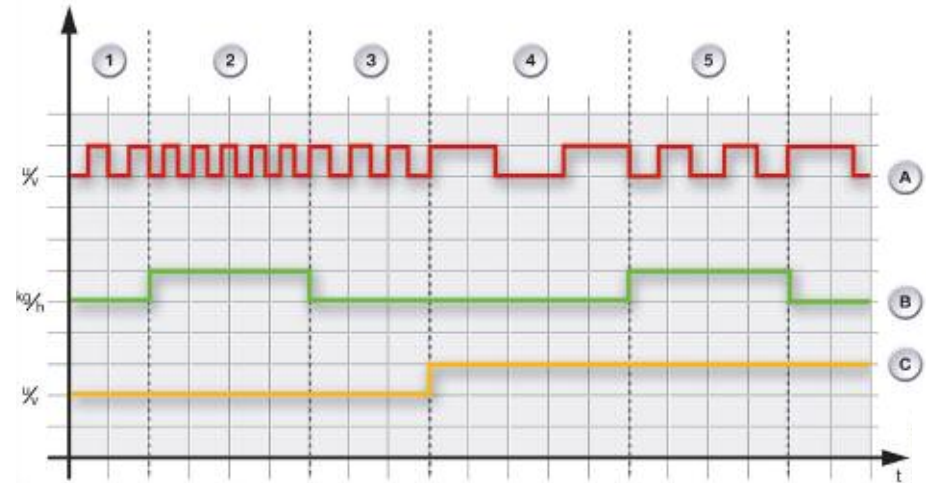
A labyrinth (6) makes sure that only the actual air mass is recorded. Thanks to the labyrinth, backflow and pulsation are not registered. In this way, the HFM determines the actual air mass irrespective of the air pressure and backflow.

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 (A) 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.

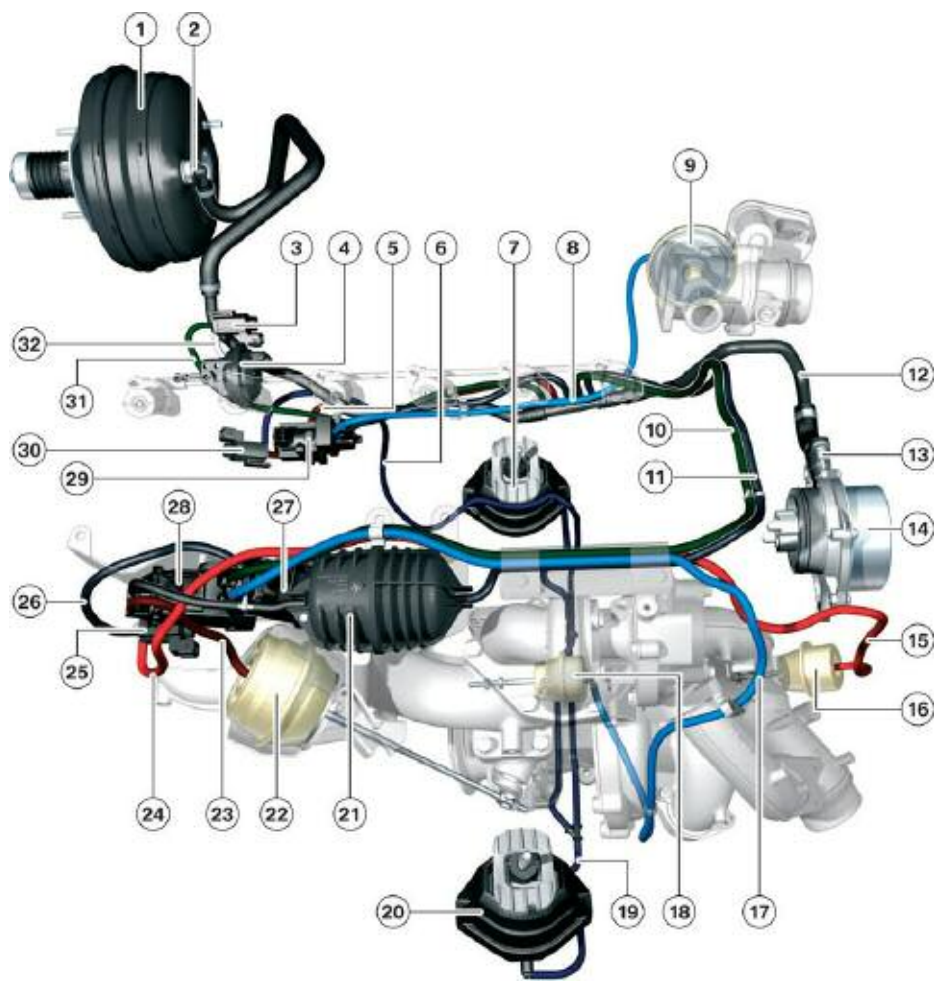
The evaluation signal fluctuates depending on the pressure. On the M57D30T2 engine, the measuring range from approximately 0.1 - 0.74 V corresponds to an absolute pressure from 50 kPa (0.5 bar) to 330 kPa (3.3 bar).



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.



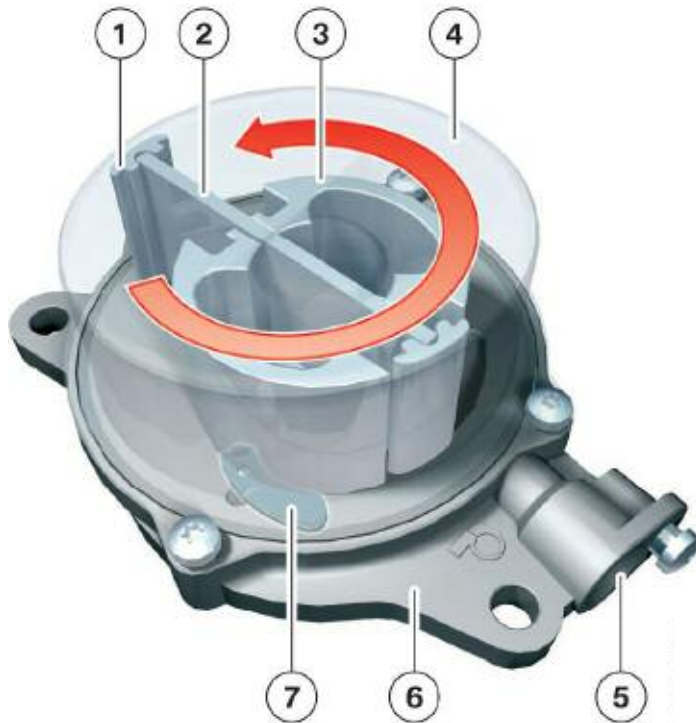
ECE Version

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, EPDW 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.

Vacuum pump

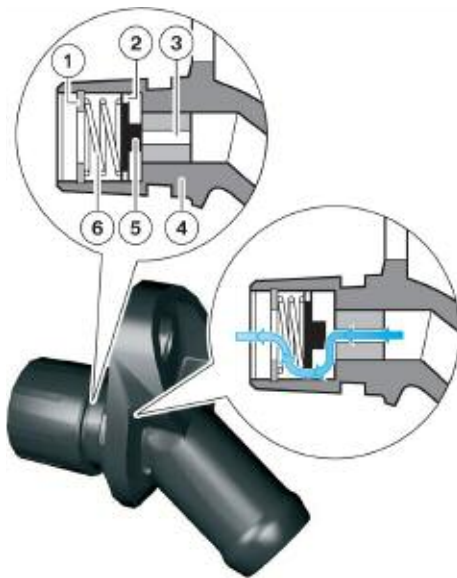


Non-return Valve

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.

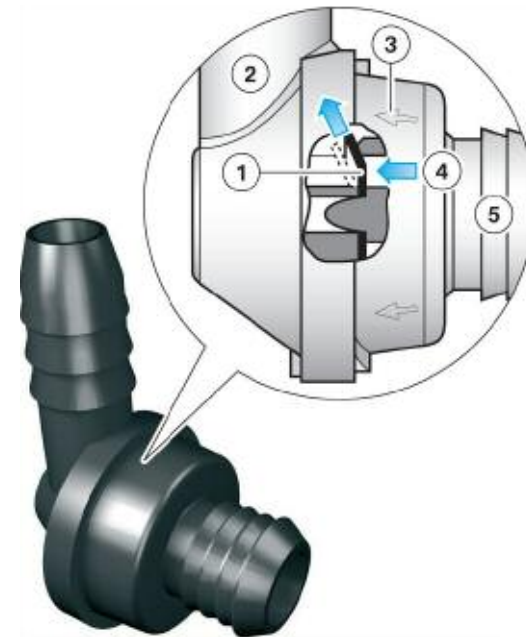


Index	Explanation
1	Retaining ring
2	Opening
3	Hole
4	Housing
5	Seal
6	Spring

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).



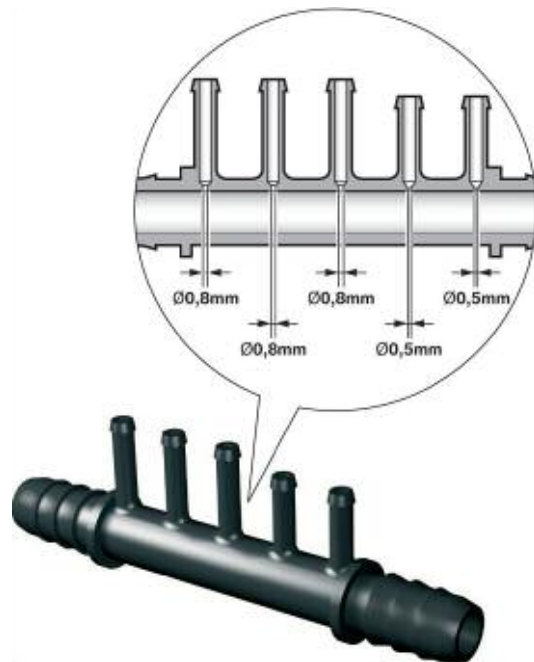
Index	Explanation
1	Valve plate
2	Vacuum connection to vacuum pump
3	Direction arrow
4	Direction of flow
5	Vacuum connection, brake booster

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:

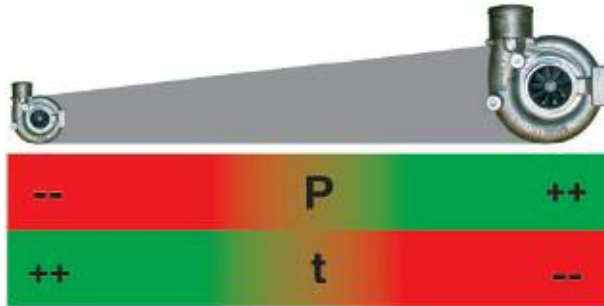
- Throttle Valve
- Swirl Flaps
- High Pressure EGR Valve
- SCR Metering Valve

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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.

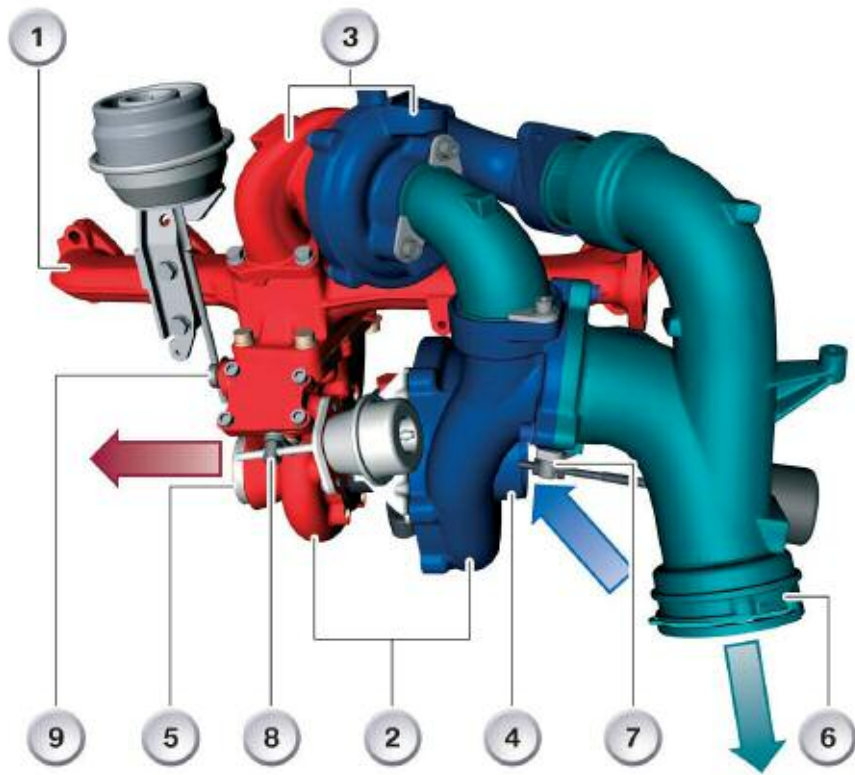
Precisely this configuration has now been developed for BMW twin turbo diesel engines. Two series-connected exhaust turbochargers are used.

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

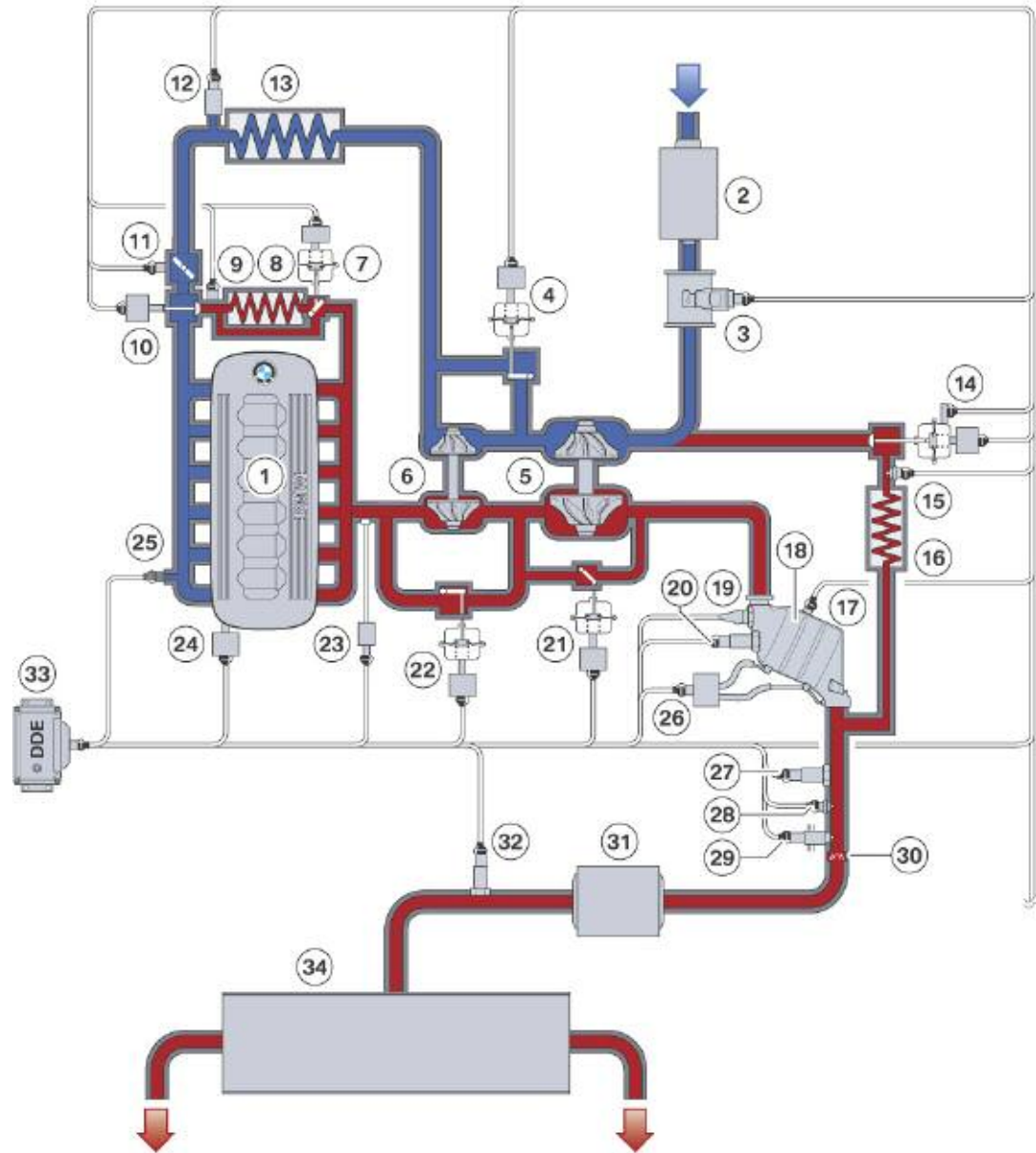
The compressor bypass valve controls the bypass of the high pressure stage on the air intake side. It is operated pneumatically by a vacuum unit. The compressor bypass valve is either fully opened or completely closed. An electric changeover valve (EUV) applies vacuum to the vacuum unit.

■ 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:

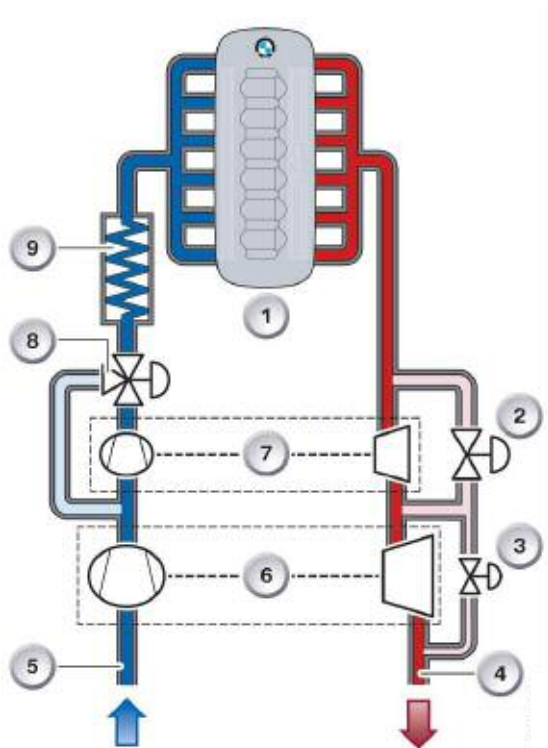
- Electric swirl flaps
- Electric exhaust gas recirculation valve (High pressure EGR valve)
- Low pressure EGR (E70 only)
- Turbo assembly adapted for low pressure EGR. (E70 only)



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)

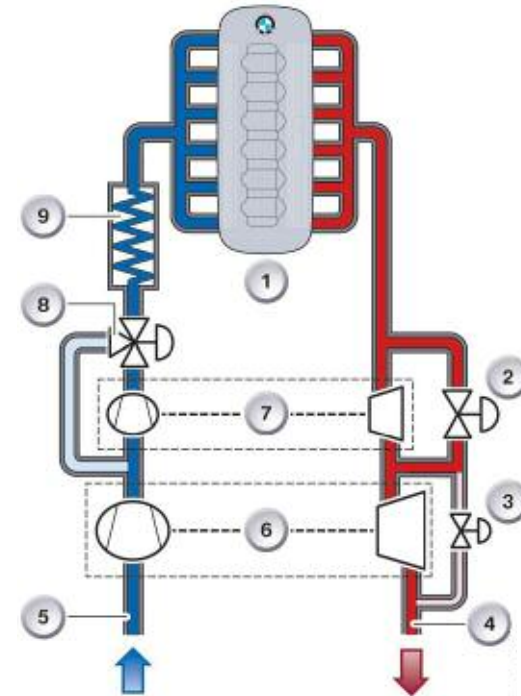
The turbine wheels of the high pressure and low pressure stages (6+7) are driven by exhaust gas. The engine is supercharged primarily by the high pressure stage (7).



■ 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).

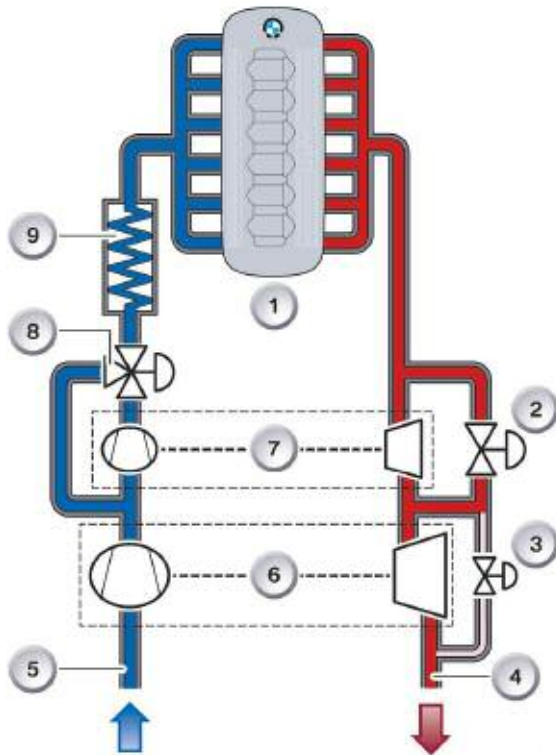
As the engine speed increases, the engine is supercharged more and more by the low pressure stage (6).



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		

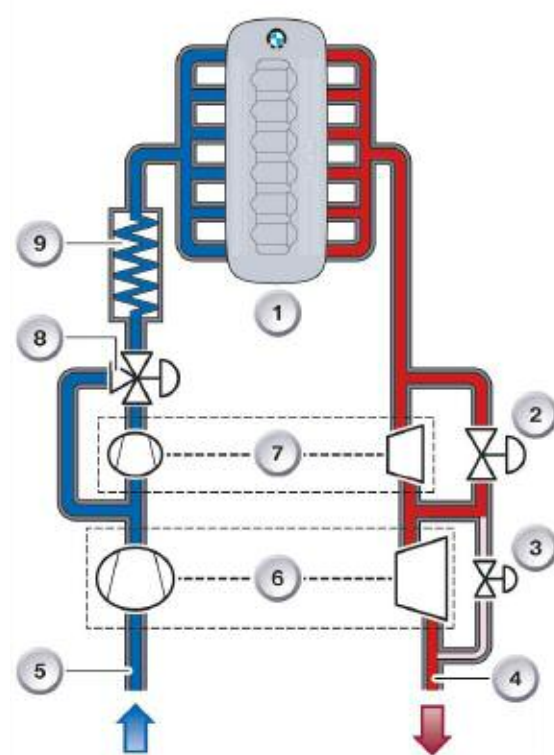
■ Upper Engine Speed Range (from 3250 to 4200 rpm)

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.



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		

Diesel Emission Control Systems

Legislation

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

Essentially, the following exhaust emission legislation applies:

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

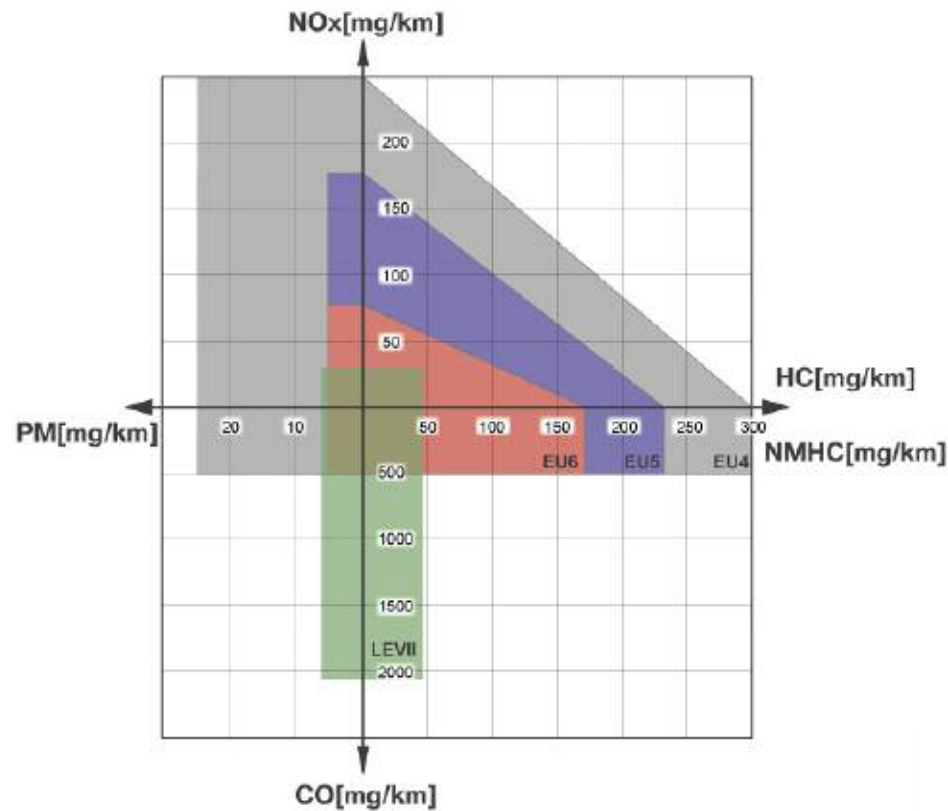
This legislation has led to the development of different requirements with regard to the limitation of various components in the exhaust gas. Essentially, the following exhaust gas constituents are evaluated:

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

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

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

Comparison of Exhaust Emission Legislation



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

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

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

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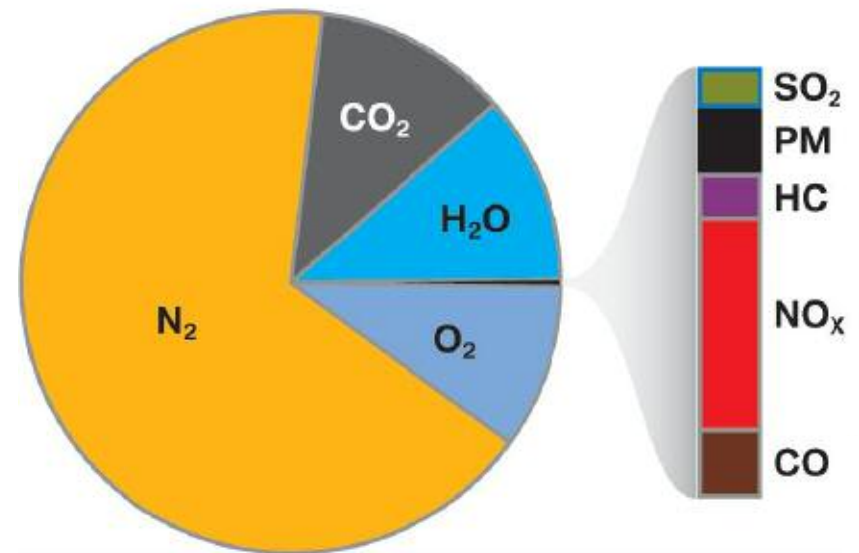
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In a diesel engine, power output is dependent upon the amount of diesel fuel injected. The engine is operated in a very lean mode with excess air. The available excess air provides enough oxygen for more complete combustion. This lean operation reduces 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.

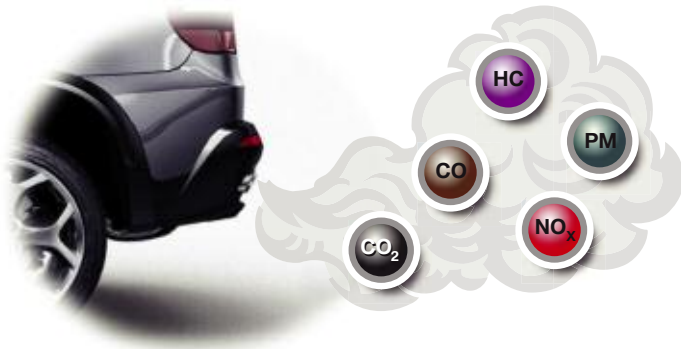
Emissions which cannot be controlled via the engine or engine management are the responsibility of the “after-treatment” system. Some of the methods employed as after-treatment systems are diesel oxidation catalysts, particulate filters and the new Selective Catalytic Reduction (SCR) systems.



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.

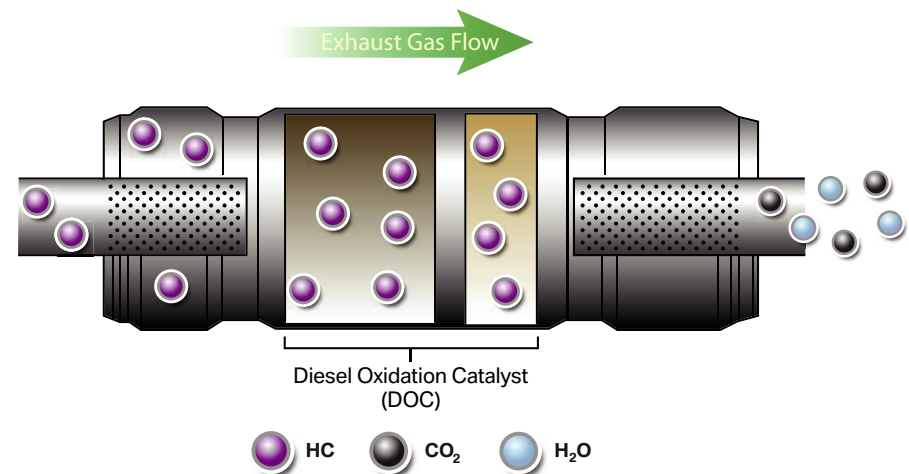
The HC is produced when there is insufficient oxygen to support complete combustion or if there are cylinder misfires. HC emissions are also produced in the “cooler” parts of the combustion chamber such as the area around the piston rings. These “cool” areas tend to quench the flame front, resulting 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.

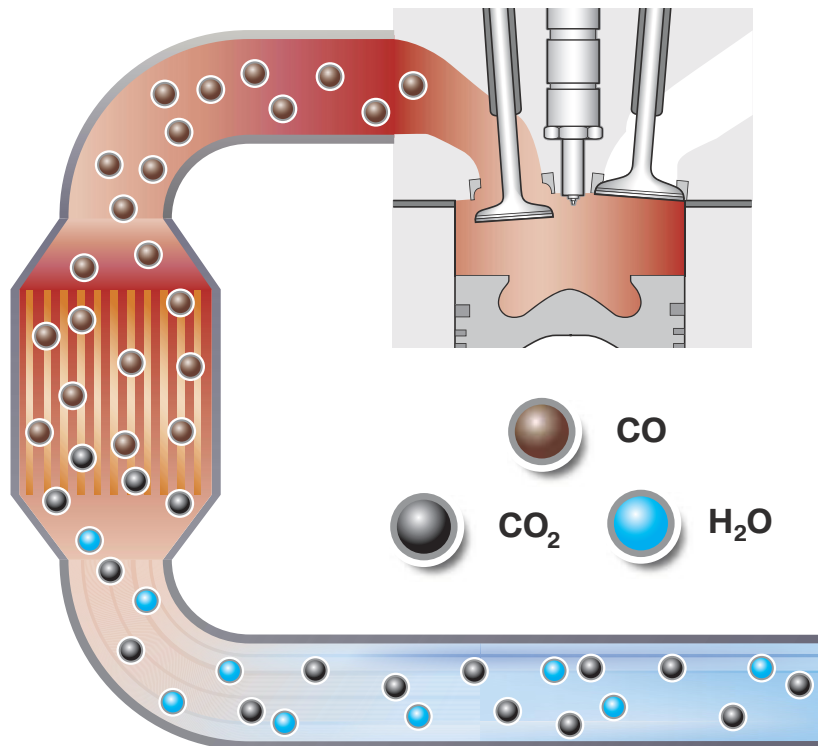
Ozone at ground level contributes to numerous health problems including lung damage and cardiovascular functions. Also, hydrocarbons are also considered toxic.



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 (CO₂) 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

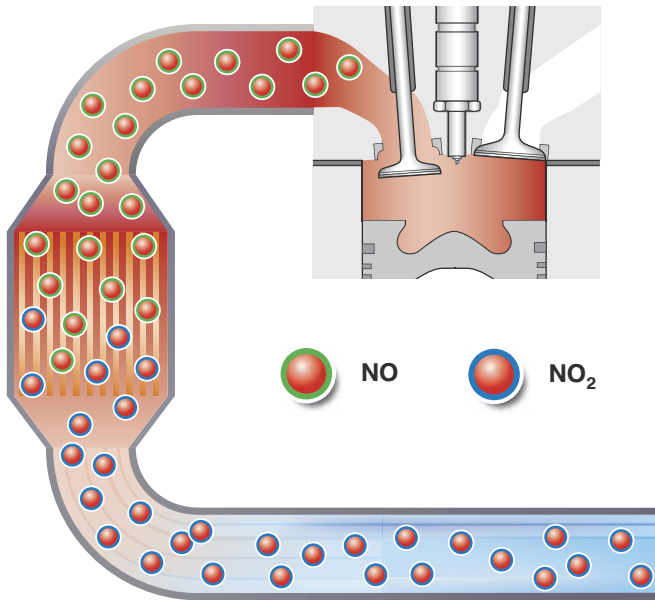
Carbon Monoxide is a colorless, odorless and tasteless gas which is poisonous to humans and other air breathing creatures. When inhaled, CO takes the place of oxygen in red blood cells. Red blood cells normally transport oxygen to all of the bodies tissues. When oxygen is substituted by CO in the bloodstream, 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 NO₂ (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.

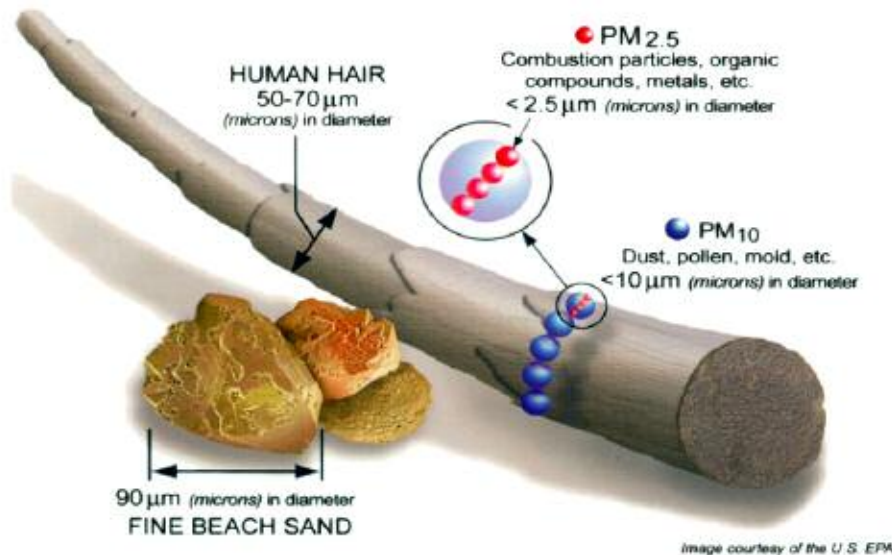
NO_x is also responsible for the formation of ground level ozone, which is also a major irritant of the respiratory system. Ozone is of particular concern to those suffering from asthma.

In the environment, both ozone and NO_x are considered to be 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, (SO₂), enters the atmosphere as a result of both natural phenomena and anthropogenic activities, e.g.:

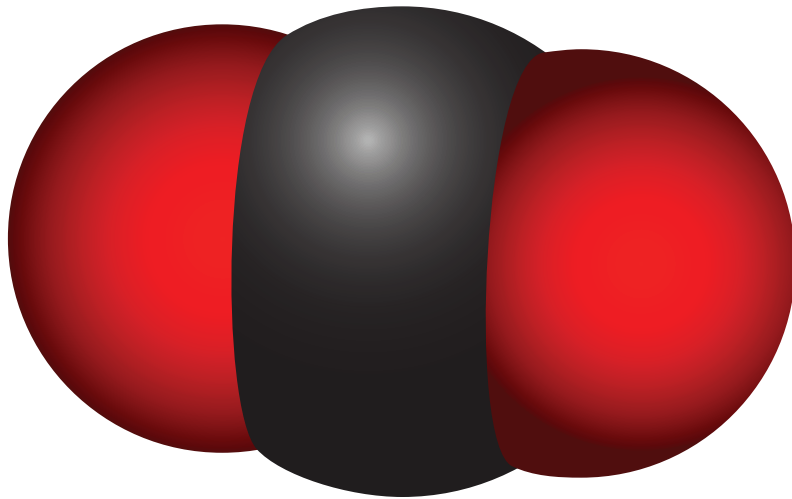
- combustion of fossil fuels
- oxidation of organic material in soils
- volcanic eruptions
- biomass burning.

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 (CO₂) 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 CO₂ content in the exhaust.

Carbon Dioxide Molecule



Ironically, CO₂ is one of the major contributors to the theory of global warming. Although CO₂ 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 CO₂ is not only the result of automobile emissions, but overall industrialization from sources such as manufacturing, power generation and transportation sectors.

Since CO₂ production in an internal combustion engine is a meas-

ure of an engine's overall efficiency, reducing CO₂ output is a challenge.

Since CO₂ 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 CO₂ output is to improve the overall efficiency.

Some of these new measures on BMW diesel vehicles include:

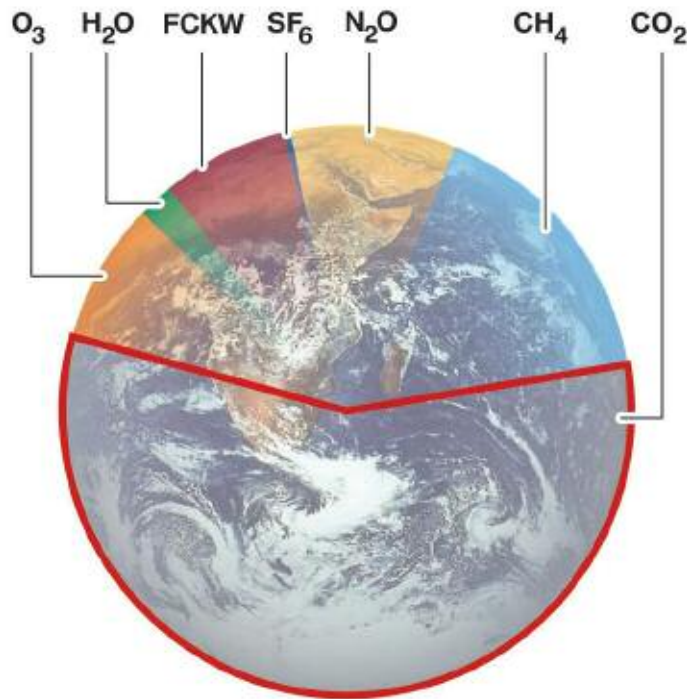
- The addition of Electric Power Steering (EPS) which reduces the parasitic load of hydraulic (belt driven) power steering
- The addition of an A/C compressor clutch (previous models omitted clutch)
- Lightweight vehicle and engine construction
- Tires with reduced rolling resistance (future)

The items mentioned above are just a few of the measures to reduce CO₂ emissions. As part of BMW's "Efficient Dynamics" concept, many new advances in "clean" diesel technology are on the horizon.

When reducing CO₂ 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.

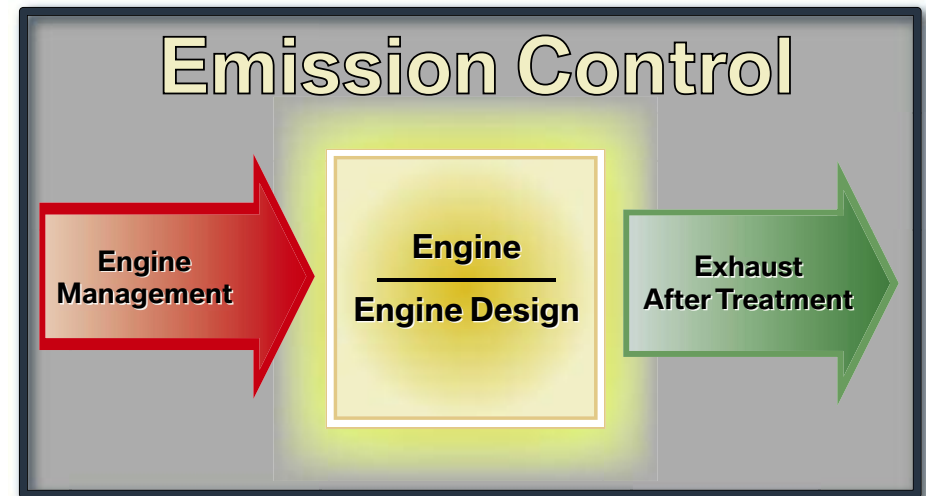
Gasoline engines run at the “stoichiometric” ratio of 14.7 to 1 otherwise known as $\lambda = 1$. Diesel engines have a variable air/fuel ratio which varies between a λ value of 1.15 to 2.0. Under idle and no load conditions this could increase to a λ value of 10.

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.

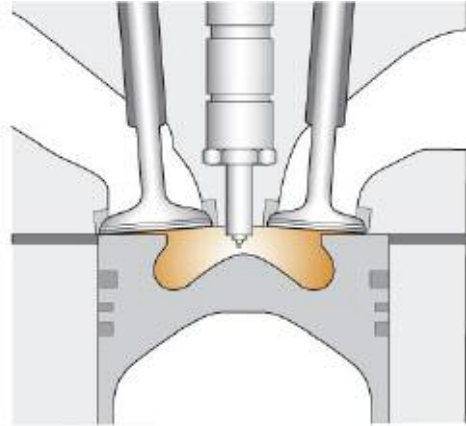
The two categories include:

- “In-engine” measures
- Exhaust after-treatment



Engine Measures to Reduce Emissions

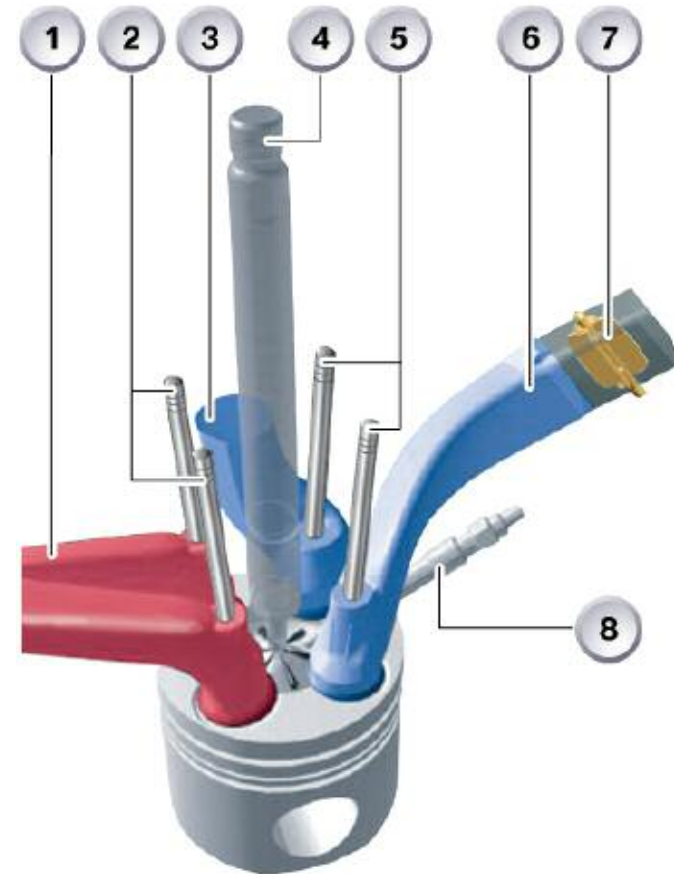
The “in-engine” measures include design elements in the mechanical structure of the engine as well as engine management intervention. In order to reduce unwanted levels of emissions, the engine design should contribute to the best possible level of efficiency.



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 lower 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 be controlled via the diesel engine management (DDE).

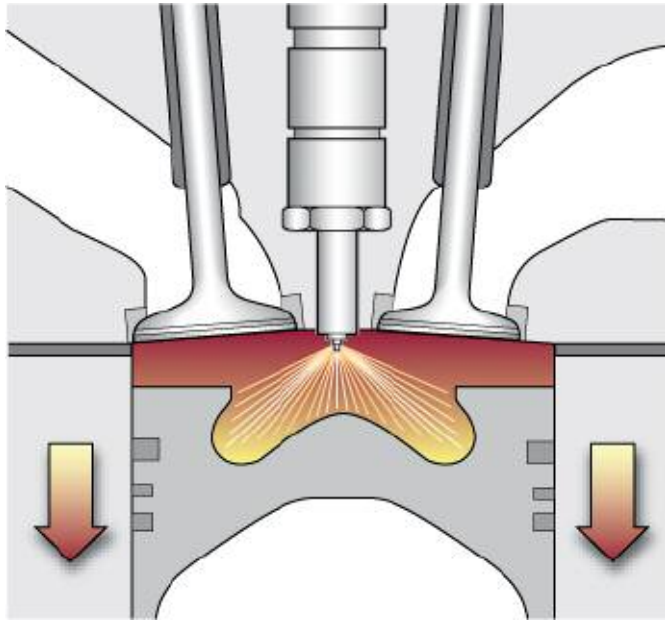
If the swirl flaps stick open, low RPM emissions will be affected. If the swirl flaps stick closed, high RPM power will be noticeably reduced.



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 discussed 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 counterproductive. 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:

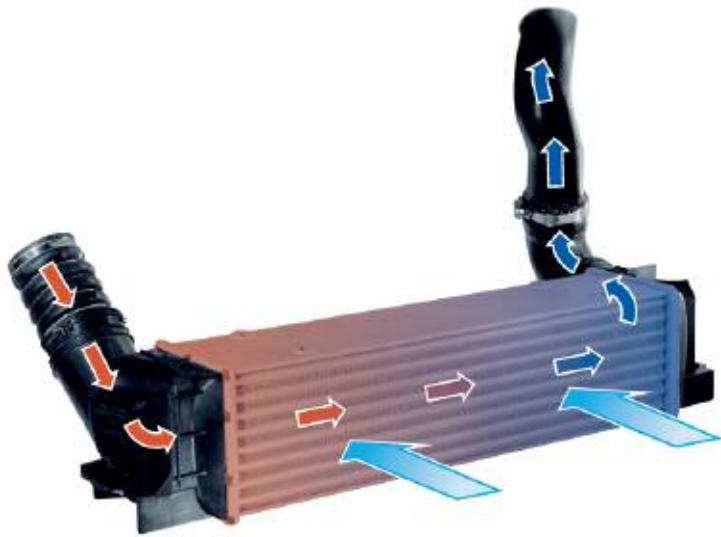
- Increased processing capacity of the DDE
- Higher efficiency of the coils in the fuel injectors

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.

NOTES

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2nd Generation Diesel Technology

Model: All with N47TU and N57TU Diesel Engine

Production: From 7/2013

OBJECTIVES

After completion of this module you will be able to:

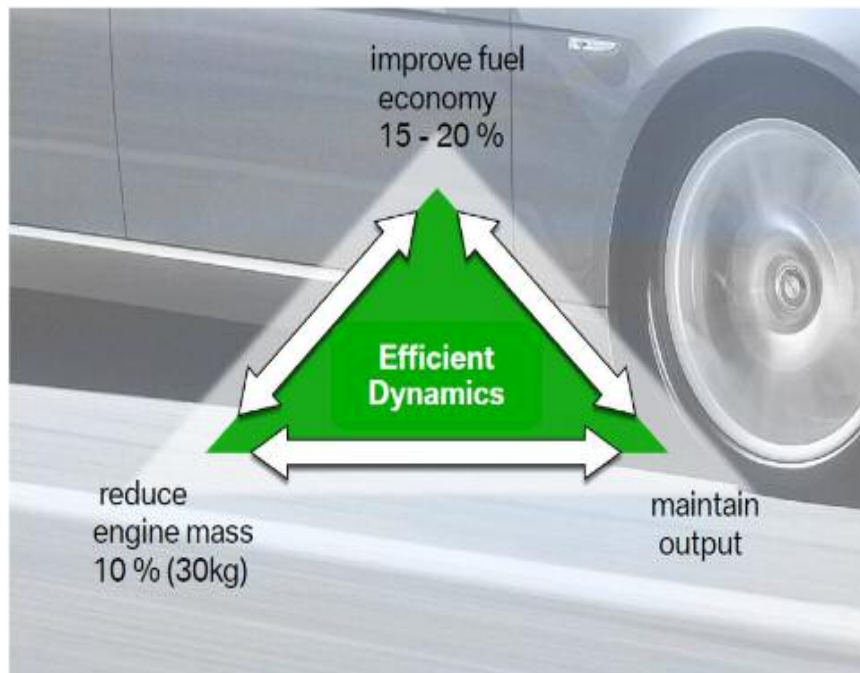
- Describe the fundamental differences between the first and second generation diesel engines.
- Identify the need for a second generation of diesel emission system.
- Understand the operating principles of second generation diesel exhaust emission control systems.
- Describe the fundamental differences between the first and second generation diesel engines and their respective emission control systems.
- Understand the required service procedures for working on the latest BMW diesel engines.

Introduction

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

This 6-cylinder diesel engine from BMW (was referred to as the M57TU2 TOP) and offered the same high level of performance that is expected from BMW drivers.

This engine was installed at the time in the 3 Series (335d) and in the X5 (xDrive35d) and have been very successful ever since their introduction in the U.S. market.



With the introduction of this engine there was a need to comply with the Tier 2, Bin 5 (LEV II) requirements and thus several emission components and systems were designed and installed on the vehicles.

Both vehicles were equipped with the latest Selective Catalytic Reduction system "BMW Advanced Diesel with Blue Performance" to reduce unwanted NOx emissions with Urea injection. An enhanced Low Pressure EGR system was especially installed in the (heavier) X5 to further assist in the reduction of NOx.

Current European and U.S. emission requirements are much more stringent than in 2008. BMW with its Efficient Dynamics strategy is once again rising to the challenge with the introduction of two new diesel engines (N47TU and N57TU). These engines are referred to as second generation diesel engines and were released in July of 2013.

In order to comply with the current, more stringent regulations, both engines include the latest in emission control and engine management technology.

Although these diesels are certified to the ULEVII (California) standard in some states the requirement is still Tier 2, Bin 5 (LEV II).



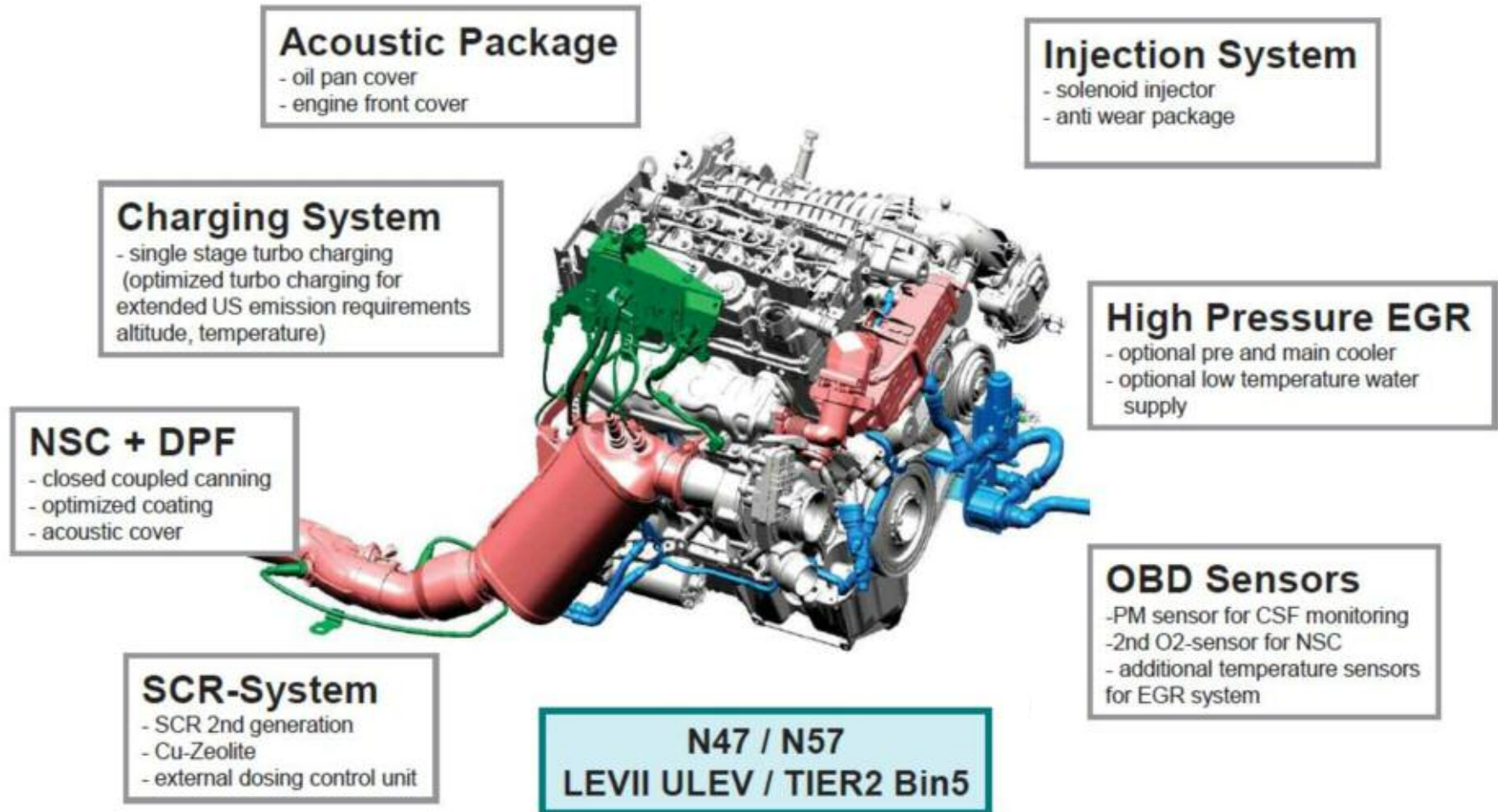
The four cylinder N47TU is installed in the 328d which was made available to the U.S. market as of 7/2013. It accelerates from 0-60 mph in 7.4 seconds while achieving a fuel economy of 32/45/37 mpg (city/highway/combined on a non xDrive vehicle).



The six cylinder engine N57TU was made available also as of 7/2013 with the introduction of the 535d and in the new X5. The F15 X5 xDrive35d accelerates from 0 to 60 mph in 6.9s and the 535d in 6.0s while offering fuel economy figures of 26/38/30 mpg (city/highway/combined on the 535d) and 23/31/26 mpg (city/highway/combined on X5 xDrive35d).



Update Overview



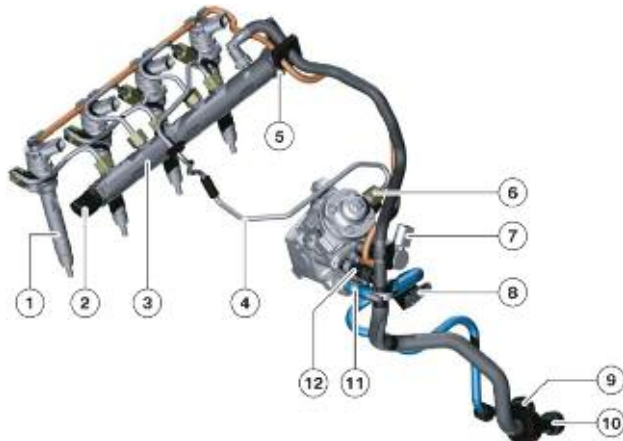
Second Generation Diesel Engines

The N47TU and N57TU share the following features:

- Common rail fuel injection with Direct Injection (1800 bar)
- Solenoid injectors
- New high pressure pump (4cyl-CP4.1 and 6cyl-CP4.2)
- VNT (variable nozzle turbine) turbocharger with intercooler
- Lightweight aluminum alloy crankcase
- EGR system with EGR cooler
- Diesel Particulate Filter (DPF)
- Particulate matter sensor
- NOx Storage Catalyst (NSC)
- Selective Catalytic Reduction (SCR) System
- Digital Diesel Electronic (DDE)

In addition to the features listed above, the both new engines also incorporate the MSA system for enhanced fuel economy.

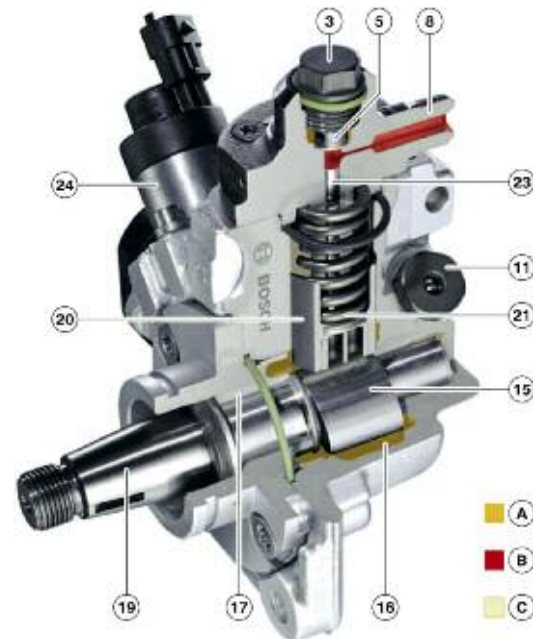
Both engines use common rail injection with solenoid injectors.



In order to comply with the more stringent emission limits for diesel engines, modern injection systems inject with ever higher pressures and with ever greater precision. The common rail system satisfies these requirements to optimum effect. In the common rail system the fuel is stored in the rail under high pressure and is injected via injectors on a map-controlled basis into the combustion chambers.

The function of the high-pressure pump is to bring the fuel from the fuel supply to the required pressure level inline with the current demand. This must be performed in all operating ranges and over the entire service life. The high-pressure pump permanently generates the system pressure for the rail (high pressure accumulator).

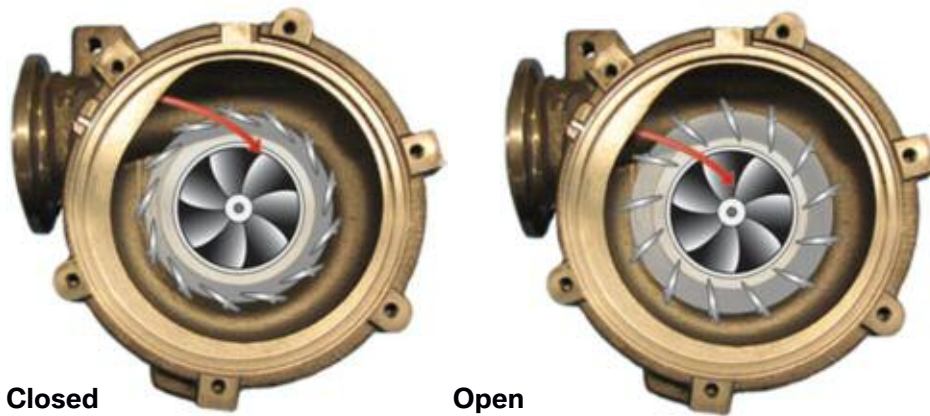
The N57TU engine is fitted with a twin-piston high pressure pump with the designation CP4.2. It is based on the design and operation of the CP4.1 single piston pump used on the N47TU engine.



Exhaust Turbocharger

Both engines use a variable nozzle turbine exhaust turbocharger (for the first time in the U.S. market).

The variable geometry exhaust turbocharger is referred to as a Variable Nozzle Turbine (VNT). The variable nozzle turbine makes it possible to alter the gas flow that drives the turbine wheel in relation to the engine operating point varying the cross-flow section in the turbine wheel inlet housing using variable guide vanes.



When the VNT vanes are in the “closed” position (see graphic on the left) the transfer of energy to the turbine wheel and compressor is increased due to an increase in exhaust gas pressure and an optimum angle of attack. This results in maximum turbine speed and boost pressure (beginning at low engine speeds).

This increase in boost pressure allows for a higher injection rate to be authorized by the DDE.

When the VNT vanes are in the “open” position (see right side graphic) the transfer of energy to the turbine wheel and compressor is decreased as the flow-rate and exhaust gas pressure driving the turbine decreases. This is due to a reduction in exhaust gas pressure and a less than optimum angle of attack which results in a decrease in turbine speed and boost pressure.

Therefore as the engine speed increases, the vanes are gradually opened so that the energy transfer always remains in equilibrium at the desired boost-pressure depending on engine speed and load requirements.

Advantages of VNT system:

- High torque at both high and low engine speeds.
- Continuous and optimum adjustment for all engine speeds.
- No "wastegate valve" required, the exhaust energy is better utilized as there is less back-pressure in conjunction with the same compressor work.
- Low thermal and mechanical load facilitates improved optimization of engine power output.
- Low emission values also at very low engine speeds.
- Optimized fuel consumption over the entire engine speed spectrum.

The electronically controlled VNT actuator is controlled by the DDE and is used to vary the exhaust gas driving the turbo. This results in enhanced efficiency to the point that a wastegate is not necessary.



Technical Data Comparison

Description	Units of Measurement	M57D30T2	N57D30O1	N47D20O1
Engine type		R6	R6	R4
Displacement	(cm ³)	2993	2993	1995
Firing order		1-5-3-6-2-4	1-5-3-6-2-4	1-3-4-2
Stroke	mm	90	90	90
Bore	mm	84	84	84
Power output @ rpm	hp @ rpm	265 @ 4200	255 @ 4000	181 @ 4000
Torque @ rpm	lb-ft @ rpm	425 @ 1750	413 @ 1500-3000	280 @ 1750-2750
Maximum engine speed	rpm	4800	5000	4600
Power output per liter	hp/liter	89.3	85.12	90.74
Compression ratio	ratio	16.5 : 1	16.5 : 1	16.5 : 1
Cylinder spacing	mm	91	91	91
Valves/cylinder		4	4	4
Intake valve	mm	27.4	27.2	27.2
Exhaust valve	mm	25.9	24.6	24.6
Main bearing journal diameter	mm	60	55	55
Connecting rod journal diameter	mm	45	50	50
Fuel specification (Octane)	(RON)	Diesel (Cetane 51)	Diesel (Cetane 51)	Diesel (Cetane 51)
Engine management		DDE 7.3	DDE 7.41	DDE 7.21
Emission standard		LEV II	ULEV II	ULEV II

Second Generation Diesel Exhaust Emissions Controls

The well-known systems such as selective catalyst reduction (SCR), NOx storage catalytic converter (NSC), low temperature Exhaust Gas Recirculation and diesel particulate filter (DPF) would not have been possible if not for the need to comply with the tighter EURO 6 and US emission standards.

The second generation exhaust after treatment system is identical in function to that of the M57D30T2 engine with diesel particulate filter.

However, there are differences arising due to compliance with the ULEV II emission standards. Therefore new components have been added and familiar components modified.

The major components of the new exhaust after-treatment are listed below:

- NOx storage catalyst (Catalyst)
- Oxygen sensor downstream of diesel particulate filter
- Diesel particulate filter with PM sensor
- SCR2 System
- DEF Dosing Control Unit
- Exhaust temperature sensor upstream of SCR system

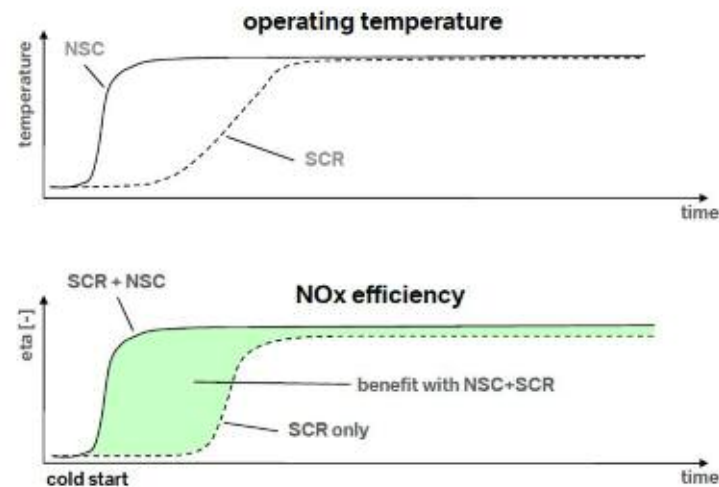
The new system uses an NOx storage catalytic converter with a newly designed sensor systems. As well as reducing nitrogen oxides, the NOx storage catalytic converter also performs the function of an oxidation catalytic converter.

The NOx storage catalyst and diesel particulate filter are housed in the same housing; that assembly is coupled to the turbocharger outlet.

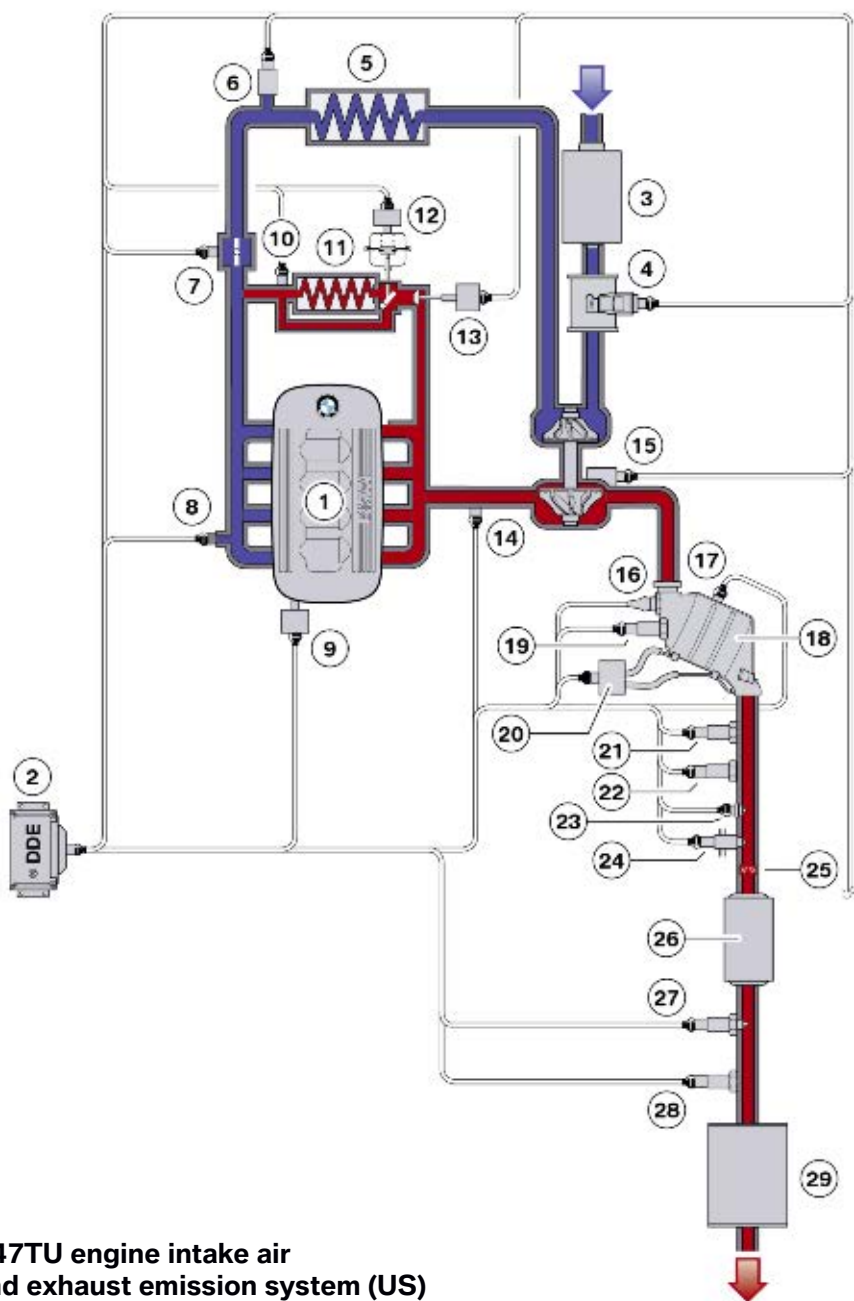
The oxygen sensor downstream of NSC/DPF in combination with the exhaust temperature sensors are used to monitor the NSC and regulate the regeneration process.

For the first time a particulate matter sensor has been installed to further monitor the diesel particulate filter and meet the more stringent particulate matter OBD2 emission testing requirements.

The new SCR system is the second generation (SCR 2) and uses enhanced urea dosing components and SCR catalyst.

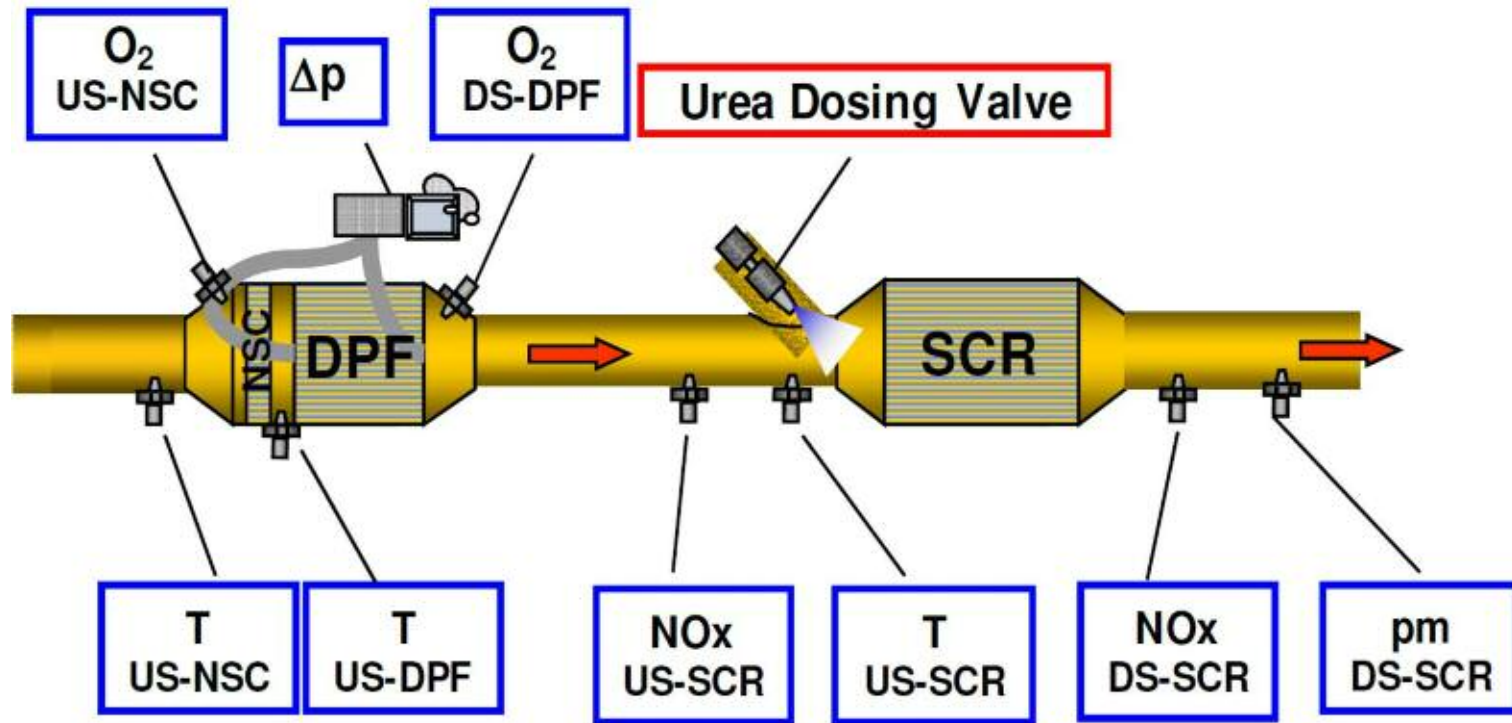


The combination of NSC with SCR has proven to be much more efficient at reducing NOx (especially in lean conditions) than the previous Oxi-Cat/SCR system.



**N47TU engine intake air
and exhaust emission system (US)**

Index	Explanation
1	Engine (N47TU)
2	Digital Diesel Electronics (DDE)
3	Intake silencer
4	Hot film air mas meter
5	Charge air intercooler
6	Charge air temperature sensor
7	Throttle valve
8	Boost pressure sensor
9	Swirl-flap actuator
10	Exhaust-gas recirculation temperature sensor
11	Exhaust-gas recirculation cooler
12	EGR cooler by-pass valve
13	Exhaust-gas recirculation valve with position sensor
14	Exhaust back pressure sensor before the exhaust turbocharger
15	Boost pressure actuator
16	Exhaust temperature sensor upstream of NOx storage catalyst
17	Exhaust temperature sensor downstream of NOx storage catalyst
18	NOx storage catalytic converter/Diesel particle filter
19	Oxygen sensor upstream of NOx storage catalytic converter
20	Differential exhaust pressure sensor before and after the DPF
21	Oxygen sensor downstream of NSC/DPF
22	NOx sensor upstream of the SCR catalyst
23	Exhaust temperature sensor upstream of SCR catalyst
24	Dosing valve
25	Mixer (SCR)
26	Selective catalyst reduction (SCR) converter
27	Particulate matter (soot) sensor
28	NOx sensor downstream of the SCR catalyst
29	Rear silencer



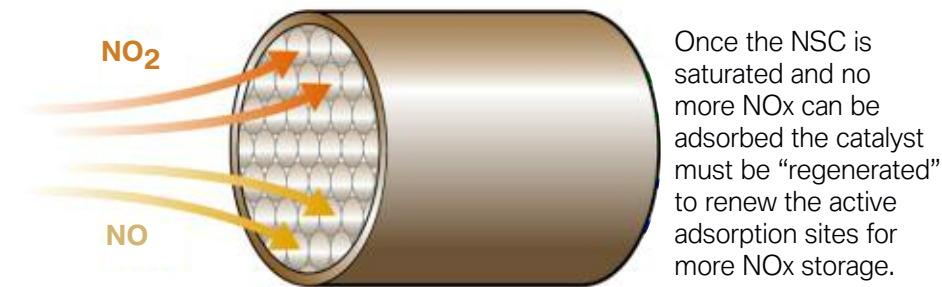
Index	Explanation
TUS-NSC	Temperature sensor up stream of the NOx Storage Catalyst
O2US-NSC	O2 sensor up stream of the NOx Storage Catalyst
NSC	NOx Storage Catalyst
Δp	Differential pressure sensor
TUS-DPF	Temperature sensor up stream of the Diesel Particulate Filter
O2DS-DPF	O2 sensor down stream of the NSC
NOx US-SCR	NOx sensor up stream of the Selective Catalytic Reduction
UDV	Urea Dosing Valve
TUS-SCR	Temperature sensor up stream of the Selective Catalytic Reduction
SCR	Selective Catalytic Reduction
NOxDS-SCR	NOx sensor down stream of the Selective Catalytic Reduction
pmDS-SCR	Particulate matter sensor down stream of the Selective Catalytic Reduction

NOx Storage Catalyst

NOx emissions are difficult to control in lean conditions. Three-way catalysts commonly used with gasoline engines do not reduce NOx when the engine runs lean. This is due to the excess heat and oxygen in the exhaust.

Due to the increasing need to limit NOx emissions from diesel engines, devices such as exhaust gas recirculation (EGR) and selective catalytic reduction (SCR) have been introduced, however EGR is limited in its effectiveness and SCR requires the use of a urea/water solution. The fluid requires special storage tanks which take up valuable space in the vehicle and if the tank runs dry the SCR system ceases to function.

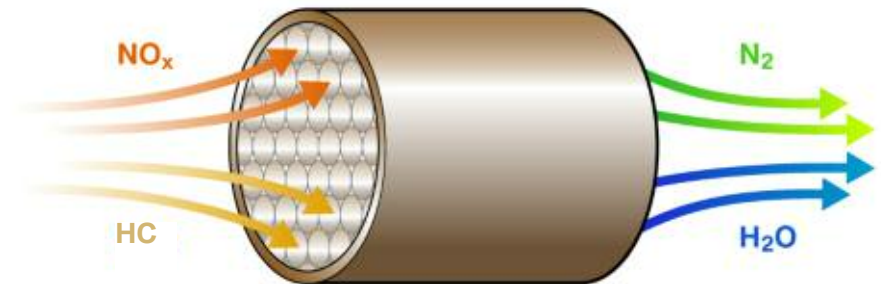
NOx Adsorption catalysts (also known as Lean NOx trap or NOx storage catalyst) are much more efficient at reducing NOx emissions in lean exhaust conditions. NOx reduction efficiencies of >85% have been documented on lean burn diesel engines.



A zeolite coating within the wash-coat of the NSC adsorbs and traps the NO₂ molecules. As NOx begins to saturate the catalyst, the NOx trapping efficiency begins to deteriorate.

Once the NSC is saturated and no more NOx can be adsorbed the catalyst must be "regenerated" to renew the active adsorption sites for more NOx storage.

Excess diesel fuel is injected into the engine to "purge" or "regenerate" the absorbed NOx. This rich mixture purges the NSC of NOx and prepares it for the next adsorption cycle (the NO₂ is easily combined with hydrocarbons to produce H₂O and N₂).



"Regeneration" occurs during rich conditions and allows the reduction of the NOx into nitrogen. The precious metal in the catalyst assists in the release and ultimate reduction of the trapped NOx.

After regeneration, the catalyst is again active and ready for NOx trapping, and the lean-rich cyclic process begins again.

The regeneration process occurs relatively fast in comparison to the NOx saturation periods observed during sorption.

Due to the rich mixture necessary to perform regeneration of the catalyst the overall fuel economy is affected.

■ Storage Phase

The exhaust produced in lean-burn mode is characterized by nitrogen oxide (NO) content and high levels of oxygen (O₂).

The consequence of that for conversion of the exhaust in the oxidation catalytic converter is that the nitrogen oxides cannot be reduced to a sufficient degree.

The exhaust gasses rich in nitrogen oxide therefore represent the raw emissions for the NO_x storage catalytic converter. They are stored on the wash-coat in the storage component in order to be converted in a subsequent process.

The capacity for storing nitrogen oxide in the storage material is limited. No further nitrogen oxide can be accepted when the storage material is completely transformed into barium nitrate.

This saturation situation is an extremely important operating point for the engine management. The engine management detects that saturation by means of a model assisted procedure. The amount of stored NO_x is calculated taking into account the catalytic converter temperature, the past driving profile and the stored figure for the thermal aging of the accumulator catalytic converter.

■ Discharge Phase

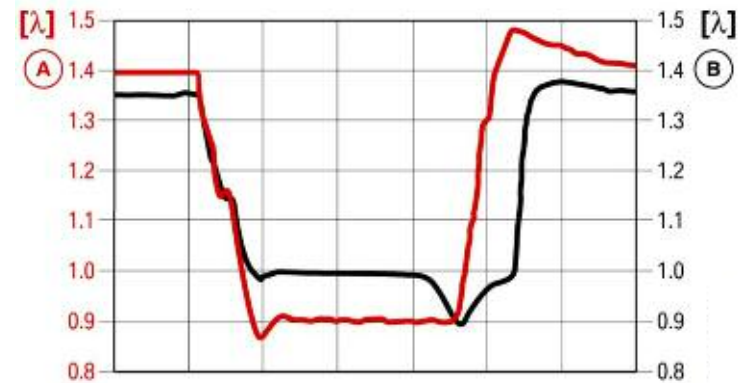
When the NO_x storage catalytic converter reaches saturation, the digital diesel engine management initiates discharge of the nitrogen oxides. To that end, the engine is switched to a slightly rich mixture of Lambda $\lambda = 0.93$.

Discharge takes place by the conversion of the barium nitrate to barium carbonate. The nitrogen oxides are then converted at the catalytic component of the storage catalytic converter.

The end of this conversion process represents another important operating point as the engine management has to know when it can end the rich-mixture running phase.

During the process, the residual oxygen content downstream of the diesel particulate filter is measured by a constant-characteristic oxygen sensor. The oxygen sensor measures the oxygen concentration in the exhaust and signals "rich-mixture changeover" from Lambda $\lambda = 1$ to Lambda $\lambda = 0.93$ when the discharge phase is complete.

Rich-mixture changeover from $\lambda = 1$ to $\lambda = 0.93$



Index	Explanation
A	Signal from oxygen sensor upstream of NO _x storage catalytic converter
B	Signal from oxygen sensor downstream of diesel particulate filter

The sulphur (S) contained in the fuel reduces the storage capacity of the NO_x accumulator catalytic converter. The sulphur forms a chemical compound with the storage agent in the catalytic converter. The barium carbonate and the sulphur combine to form barium sulphate with the result that the barium carbonate cannot absorb any more nitrogen oxides.

This process can continue to such an extent that the entire storage capacity is lost. This sulphurization process is detected by the engine management in that an initiated reduction phase does not result in effective reduction of nitrogen oxides.

When sulphurization is detected, the catalytic converter temperature must be raised to between 650 °C and 720 °C to allow the barium sulphate to be converted back to barium carbonate and consequently to discharge the sulphur stored in the storage component. The graph shows that the total storage capacity depends both on the thermal aging and the degree of sulphurization. The storage capacity is increased by the desulphurization process.

The ability of the NO_x accumulator catalytic converter to absorb nitrogen oxides and therefore its aging depends on:

- Fuel quality of sulphur in the fuel
- Operating temperatures of the catalytic converter



Storage capacity reduction of NO_x storage catalytic converter with regard to sulfur.

Index	Explanation	Index	Explanation
A	Storage capacity	3	Total storage reduction
B	Distance (Km)	4	Sulphurization
1	Thermal aging	5	Desulphurization
2	Storage capacity reduction through sulphurization		

Diesel Particulate Filter with PM Sensor

The new generation DPF operates in similar fashion as the previous system. The exhaust gases flow out of the NSC 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 burned off 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. However, the optimum conditions are not always present in sufficient time intervals to remove soot, so a filter regeneration phase can be induced by the DDE periodically.

The following sensors are installed:

- Exhaust temperature sensor upstream of diesel particulate filter
- EGR temperature sensor
- Oxygen sensor downstream of diesel particulate filter (new)
- Particulate matter sensor (new)

The exhaust temperature sensor upstream of the diesel particulate filter enables even more precise control of particulate filter regeneration.

Filter regeneration requires an exhaust temperature of 240 °C. Initiating filter regeneration below 240 °C would result in white smoke emission due to surplus hydrocarbon (HC). The exhaust temperature sensor upstream of the oxidation catalytic converter makes it possible to prevent regeneration until the temperature exceeds 240 °C.

The exhaust temperature upstream of the diesel particulate filter is registered for the purposes of controlling post-injection and thereby the exhaust temperature itself upstream of the diesel particulate filter. With the aid of the exhaust temperature sensor upstream of the diesel particulate filter, the temperature is regulated by way of the post injection volume to a level of between 580 °C and 610 °C depending on vehicle model.

The EGR temperature sensor is required in order to be able to precisely determine the mass flow rate of the recirculated air. Using it in conjunction with the hot-film air mass-flow sensor and the exhaust back-pressure sensor upstream of the turbocharger, the recirculated air mass flow rate can be precisely determined. As the recirculated exhaust can also be fed back into the intake manifold uncooled in order to raise the temperature, measuring the temperature of the recirculated exhaust also serves as a safety feature for the intake system which protects it from excessive temperatures.

Such measures are required because the engine has to be run intermittently for up to 3 seconds with a rich mixture of $\lambda \approx 0.93$ in order to reduce nitrogen oxides and sulphating of the NOx accumulator catalytic converter.

In addition, for the first time there is also a particulate matter sensor (located downstream of the SCR) to monitor the actual particulate matter (soot) that escapes the system at all times. This sensor is used to determine and manage the efficiency of the diesel particulate filter (DPF) as required by the new OBD standards.

Particulate Matter Sensor

Diesel particulate filter is an essential component of the exhaust after-treatment system of all current BMW diesel engines.

Monitoring and diagnosis of the DPF (as with all emission control) is required in order to ensure its efficiency. This was done (in the previous system) via a differential pressure measurement which determines the pressure drop within the DPF. This pressure monitoring method is no longer sufficient to meet the tighter regulations regarding the OBD II diagnosis of the DPF.

On board diagnostics requirements regarding CARB legislation for DPF-OBD on Light duty Vehicles are:

- **2004-2009:**
5 x certification limit (10 mg/mi) = 50 mg/mi
- **2010-2012:**
4 x certification limit (10 mg/mi) = 40 mg/mi
- **2013 -> :**
1.75 x certification limit (10 mg/mi) = 17.5 mg/mi

In order to increase the accuracy of the DPF diagnosis and comply with these new OBD regulations BMW has designed a particulate matter sensor to detect any particulate matter in the exhaust gas that escapes the DPF.

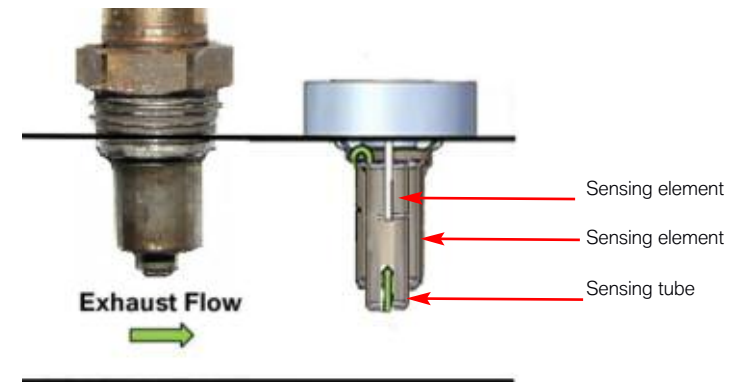
In vehicles with the N47TU and N57TU the PM sensor is located after the SCR. Due to its location the sensor needs to stand up to many exhaust hazards including ammonia and urea from the SCR system.

This location also affects the sensor's ability to reach its necessary dew point. During this time the sensor sits idle and cannot be used to detect particulates.

The PM sensor is very similar to a NOx sensor with regard to the construction of the body and that it also uses its own control unit. It has a 24 mm spin nut and an upper assembly to protect the wiring.

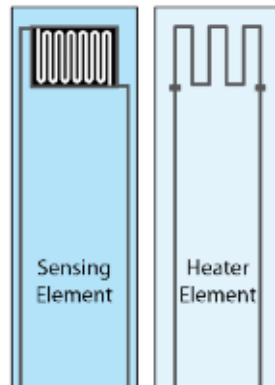


Its internal sensing element is installed in the sensing tube and protected by a outer heat shield tube which helps to guide exhaust gas flow to the sensing element.



The sensor element is a non conductive alumina-based ceramic substrate with a sensor electrode pattern made from a conductive precious metal (generally Platinum) in order to withstand the exhaust gas temperatures.

This sensing element incorporates an integrated heater near the sensing electrodes.



Integrated resistor is used as a sensing element

Integrated heater is used to regenerate the sensing element

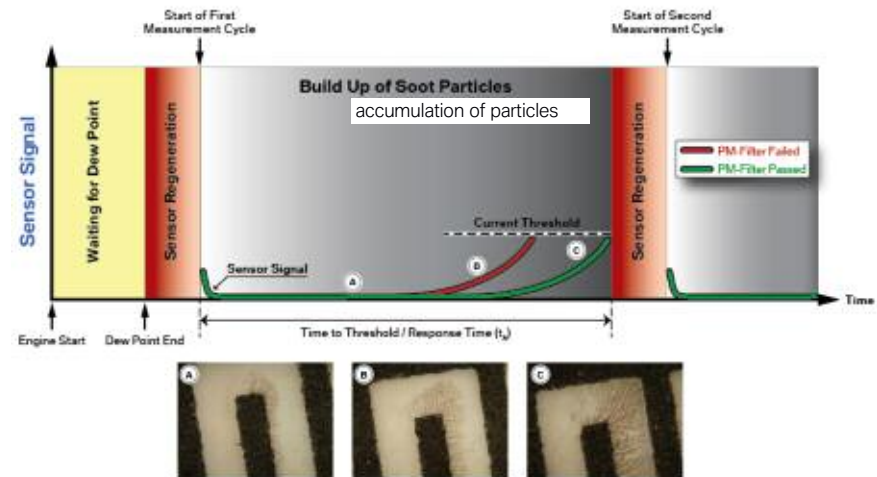
The sensor is installed so that the inlet port of the shield is located directly in the center of the exhaust flow. This places the sensing element in an optimum location to collect the best soot sample.

These (electrolytically conductive) soot particles accumulate on the sensing element surface in the space between the electrodes. This is interpreted by the control unit as a large amount of soot in the exhaust. Therefore when there is a lower amount of soot in the exhaust (less soot particles are accumulated on the sensing element) the continuity between the electrodes is less.

The initial resistance of the sensor changes as the sensing element collects soot to make a measurement. After the measurement is completed the soot must be removed and the resistance of the sensor element must be returned to its pre measurement value.

This is achieved by heating the element with the internal heater. The soot is then burned off in the regeneration process and the initial resistance of the sensing element is once again restored. The sensor is now ready for another sampling event. This sensing and regeneration cycle runs continually through the operation of the sensor.

DPF Monitoring, PM-Sensor Measurement Cycle (Principle)



After the “dew point” is reached the sensor element gradually collects soot particles. This lowers the resistance across the electrodes which causes an increase of the measured current. The PM sensor control unit monitors and sends the current signal to the DDE. The DDE then compares the amount of time that the signal takes to reach the specified threshold current and based on this evaluates the efficiency of the DPF. Therefore if the current signal reaches the threshold before the predetermined time the DPF has failed.

The heater circuit is very similar to the heating circuit of an oxygen sensor and it is powered by 12 volts. The sensing element circuit is supplied a 5V reference which is evaluated by the DDE by monitoring the resistance and calculating the current across the electrodes.

Oxygen Control

The M57D30T2 engine uses only one oxygen sensor. It is a Bosch LSU 4.9 broadband oxygen sensor and is located at the inlet to the shared housing of the diesel particulate filter (DPF) and oxidation catalytic converter.

The broadband oxygen sensor upstream of the catalytic converter constantly measures the residual oxygen in the exhaust gas. The fluctuating values of the residual oxygen are sent to the DDE in the form of a voltage signal.

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 DDE corrects the mixture composition through fuel injection based (in part) on the feedback of the O₂ sensor and the air mass (HFM).

The DDE compares this information to data points in a characteristic map that refers to the mean quantity value adaptation (MMA). The mean quantity adaptation serves to adapt the exhaust-gas recirculation more precisely to tolerance in the fuel injection rates.

The second generation diesels also use the Bosch LSU 4.9 broadband oxygen sensor. It is installed before the NSC/DPF and also operates as described above.

However the new system now incorporates a second Bosch LSU 4.9 broadband oxygen sensor located downstream of the Diesel Particulate Filter. This downstream sensor is of the same type as the front sensor but has a different part number and cable length (they are NOT interchangeable).

This second oxygen sensor enables the system to detect whether the NO_x storage catalytic converter needs to be regenerated.

Exhaust Temperature Sensors

The exhaust temperature sensor is designed as an NTC resistor sensor (the resistance decreases as temperature increases).

The previous system used two exhaust temperature sensors to monitor the operation and efficiency of the oxidation catalyst.

The new generation system also uses these temperature sensors: one is located upstream of the NO_x storage catalytic converter and the other upstream of the diesel particulate filter.

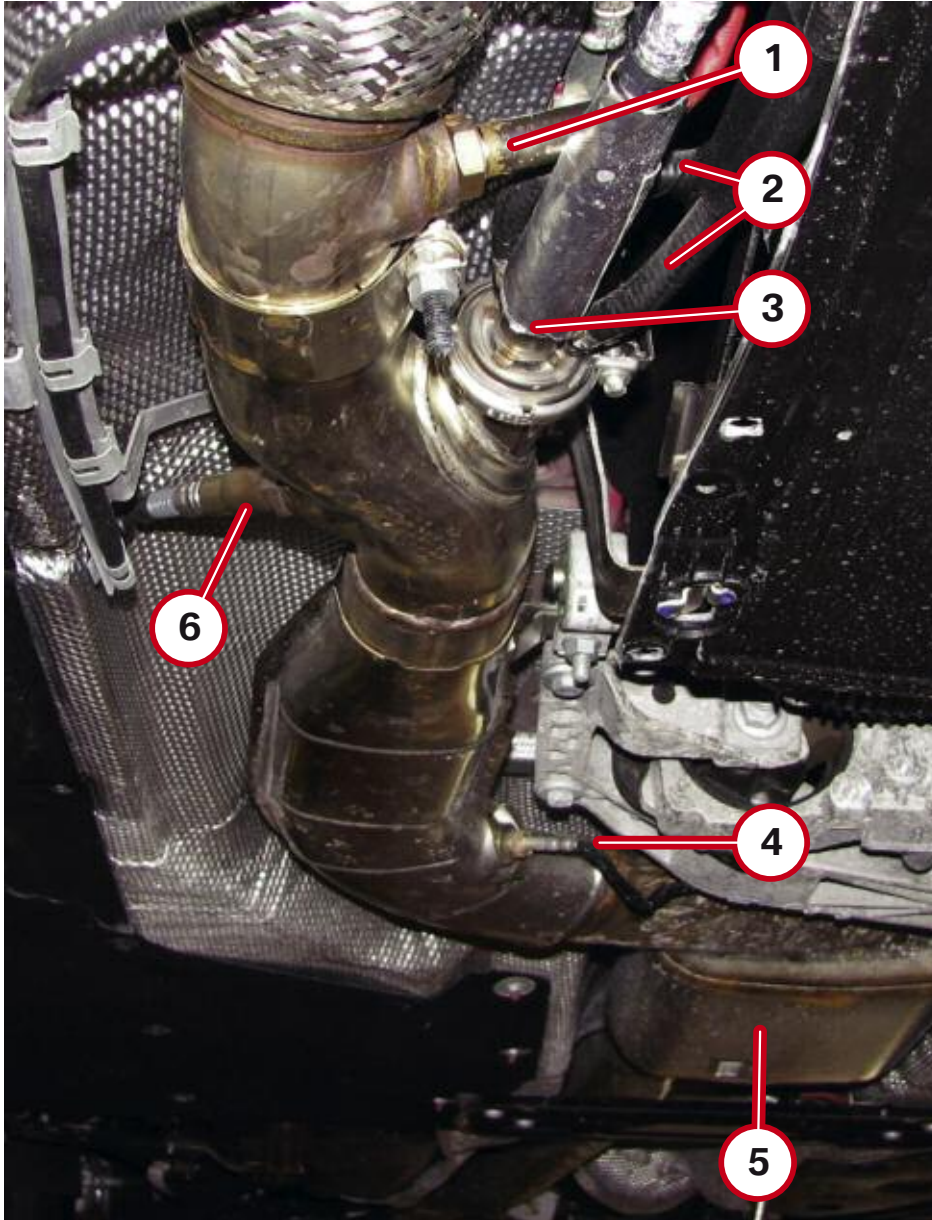
The exhaust temperature sensor upstream of the diesel particulate filter enables even more precise control of particulate filter regeneration.

The new SCR system (SCR 2) uses its own exhaust temperature sensor. It is located up stream of the SCR catalyst and it is designed to monitor the exhaust temperature near the dosing valve and send feedback to the dosing control unit (DCU). (see SCR2 section for more information)

EGR temperature sensors are also used with the second generation engines. Two EGR temperature sensors are installed if the vehicle has a low pressure EGR system.

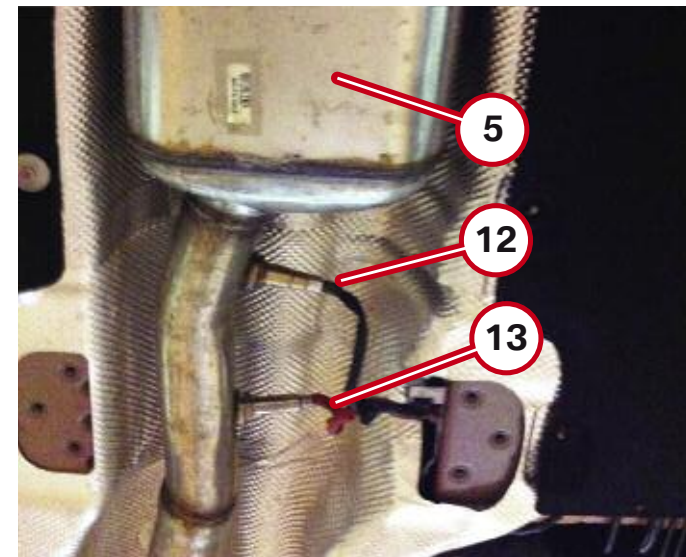
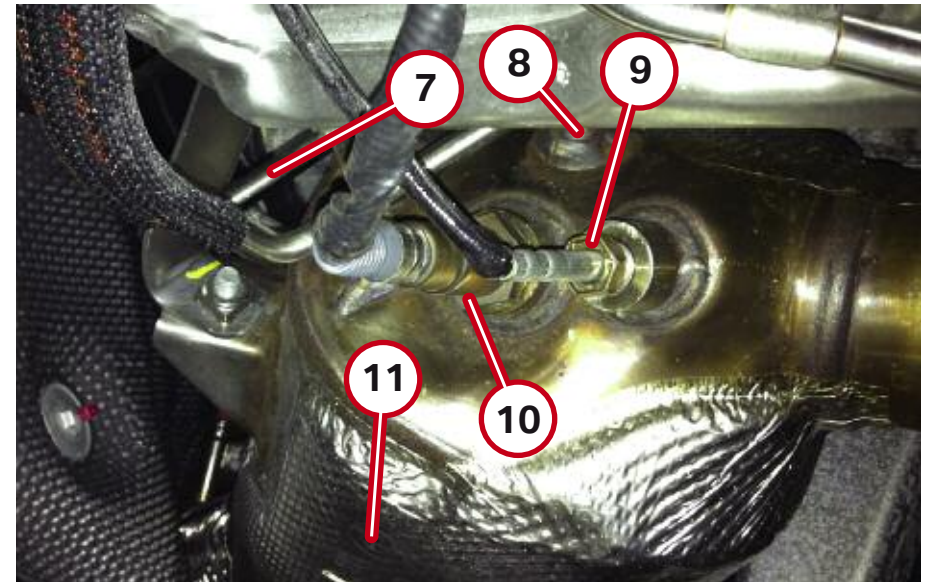
The EGR temperature sensor and the exhaust back-pressure sensor upstream of the turbocharger in conjunction with the charge pressure sensor make it possible to exactly control the exhaust recirculation rate. (See the EGR section for more information).

Exhaust System



F30 exhaust after-treatment components

F30 NSC/DPF view from engine compartment



F30 SCR Catalyst view from underbody center

Index	Explanation
1	NOx sensor upstream of NOx storage catalytic converter
2	Dosing valve (engine coolant lines)
3	Dosing valve
4	Exhaust temperature sensor upstream of NOx storage catalytic converter
5	SCR catalytic converter
6	Oxygen sensor downstream of diesel particulate filter
7	Differential pressure lines before DPF
8	Differential pressure lines after DPF
9	Exhaust temperature sensor upstream of NOx storage catalytic converter
10	Oxygen sensor upstream of NOx storage catalytic converter
11	NOx storage catalytic converter
12	Particulate matter sensor
13	NOx sensor downstream of NOx storage catalytic converter

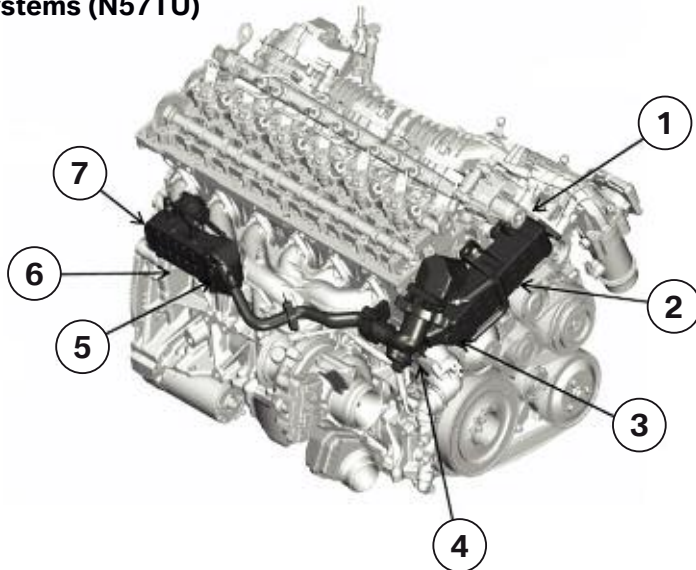
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Exhaust Gas Recirculation

The recycling of exhaust gases is one of the methods used to reduce NO_x in internal combustion engines. 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 N47TU and the N57TU. Both engines use the “high-pressure EGR”, but the six cylinder uses an additional “EGR” system.

High and Low pressure EGR systems (N57TU)



Index	Explanation	Index	Explanation
1	Main EGR cooler (High pressure 2nd stage)	5	EGR temperature sensor
2	EGR temperature sensor	6	Cooler bypass
3	Main cooler bypass	7	AUX EGR cooler
4	EGR valve		

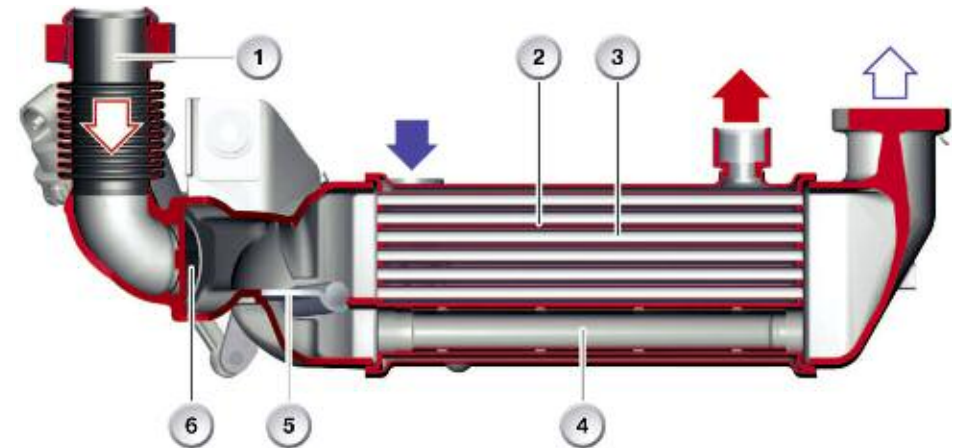
High Pressure EGR

As with the previous diesel engine 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.

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.

N47 High pressure EGR cooler



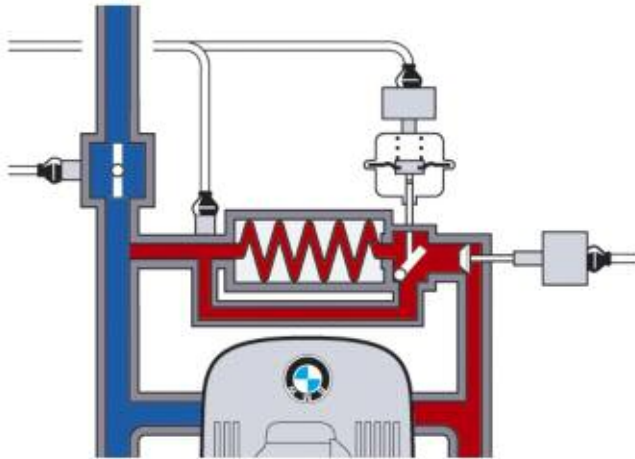
Index	Explanation	Index	Explanation
1	EGR supply from the exhaust manifold	5	EGR cooler by-pass
2	Cooling passage	6	By-pass valve
3	EGR duct		

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 Valve

The EGR valve controls the return of exhaust gas to the air intake system. It is located upstream of the EGR cooler and therefore subjected to high thermal loads. However, the component itself is not cooled.

The EGR valve is electrically operated by a stepper motor and closed by the force of a spring. Electrical EGR valves are much more sensitive to thermal load.

The EGR valve has an integral position sensor, its position is reported back to the DDE control unit. The position sensor enables the exhaust recirculation rate to be very precisely adjusted.

The EGR valve is controlled by the DDE by means of a pulse width-modulated signal (PWM signal).

The PWM signal determines the opening dimension of the valve. In this way, it is possible to have a defined volume of exhaust gas recirculated. With a pulse width of 10%, the EGR valve is fully closed and, at 90%, it is fully open.

■ EGR Cooling

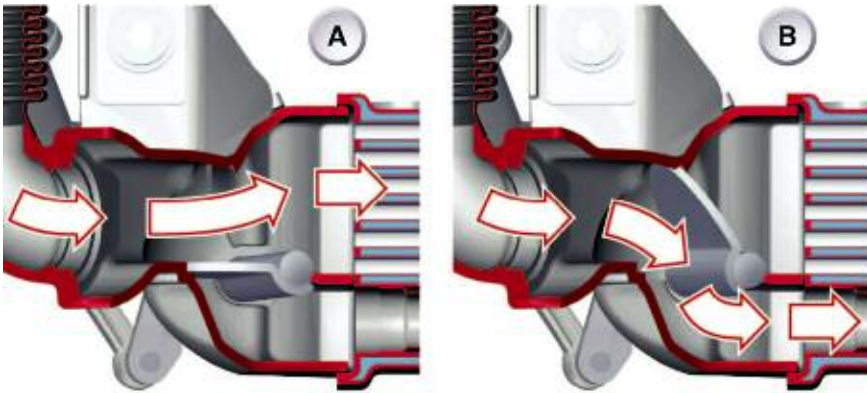
The use of an EGR cooler increases the efficiency of exhaust gas recirculation. The cooled exhaust gas is able to draw off more thermal energy from the combustion and thus reduce the maximum combustion temperature.

The EGR cooler is located downstream of the EGR valve. The engine's coolant flows through it. The exhaust gas is fed through this coolant flow in several flat pipes (almost rectangular cross section). In the process, its thermal energy is transferred to the coolant.

The EGR cooler designs are identical for the N57TU and the N47TU. Both use the same P/N for the HP EGR cooler and valve.

The EGR cooler is equipped with a bypass valve, which allows the exhaust gas to bypass the EGR cooler when required.

This is useful in the engine warm-up phase for bringing the catalytic converter up to its operating temperature more rapidly.



The bypass valve is actuated by a vacuum canister. There are only two states: open and closed. The vacuum canister is controlled by an electropneumatic changeover valve, which in turn is controlled by the DDE.

With no negative pressure, the bypass valve is closed, i.e. the exhaust gas flows through the EGR cooler. If negative pressure is present, the bypass valve opens the bypass (located inside the housing of the EGR cooler) and at the same time closes the supply to the EGR cooler.

Exhaust Gas Recirculation (EGR) Control

Under certain engine operating conditions, a certain amount of exhaust is fed back into the intake manifold by the EGR valve for the purposes of reducing exhaust emissions.

The volume of the recirculated exhaust gas influences the mass of the intake fresh air: The more exhaust gas is recirculated, the less fresh air is taken in. It is known how much fresh air mass the engine takes in at any given operating point with EGR switched off.

The reduction in the intake fresh air mass caused by the exhaust gas recirculation is therefore a measure of the volume of the recirculated exhaust gas. The system is controlled in such a way that the specified air mass flow rate for the operating situation is drawn in.

The DDE control unit calculates a target fresh air mass for each operating point from the following influencing variables:

- Engine speed
- Injected quantity
- Coolant temperature
- Atmospheric pressure
- Intake air temperature
- Reduction in the exhaust gas recirculation caused by idling for longer than 5 minutes.

The DDE control unit cannot precisely determine the mass flow rate of the recirculated exhaust because the hot-film air mass-flow sensor only measures the flow rate of the intake air and has a wide tolerance band for system design reasons.

The exhaust recirculation rate is controlled by operating the EGR valve but without an exhaust recirculation sensor and relatively imprecisely. The oxygen sensor detects whether too much or too little exhaust is being recirculated. The exhaust recirculation rate is then readjusted according to the information from the oxygen sensor.

The EGR temperature sensor and the exhaust back-pressure sensor upstream of the turbocharger in conjunction with the charge pressure sensor make it possible to exactly control the exhaust recirculation rate. Thus substantially improved control of the quantity of recirculated exhaust and, therefore, of the NO_x content of the exhaust is possible.

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Selective Catalytic Reduction 2 (SCR 2)

The SCR system was originally designed for the first generation diesel vehicles (2008) and their implementation in the US market to comply with ever so stringent CARB emission regulations but was later used to comply with the EURO 6 European standard.

In order to meet the newest guidelines, a new (updated) Selective Catalytic Reduction (SCR2) system is installed in combination with the second generation diesel engines (N47TU and N57TU).

SCR2 is model-specific and is being used for current BMW diesel engines in the USA as well as in Europe. Although the new US market diesels will be certified to the more stringent ULEVII (California) standard in some states the requirement is still Tier 2, Bin 5 (LEV II). Compliance with these regulations would not have been possible solely with the systems already known, such as NSC (NOx storage catalytic converter), EGR (low-pressure exhaust-gas recirculation), DPF (diesel particulate filter) and the internal engine measures.

SCR2 is currently the most effective system for the reduction of nitrogen oxides in the exhaust gas. However, to meet these much more stringent regulations SCR is used in combination with the previously mentioned emission systems. Therefore the requirements of the exhaust emission standards are also fulfilled in the cold-start phase, when the SCR system is not yet operational.

As already known from the previous system, the special feature of the SCR system is the use of the urea/water mixture (AdBlue®) to reduce NOx in the exhaust system. This creates a necessity to store a supply of this liquid mixture in the vehicle. This urea/water mixture is generally known under the brand name “AdBlue®” The system is managed at BMW under the marketing name “BMW BluePerformance”.

Differences Between SCR 2 – SCR

The SCR 2 was introduced to save components in comparison to the first generation. The advantages are cost savings and reduction in the variants, such as the same DDE control unit can now be used for all series. If the SCR system is installed, a SCR dosing control unit (DCU) is also installed.

The SCR 2 differs to the SCR of the first generation primarily by the following characteristics:

- SCR 2 control is housed in its own SCR control unit (DCU, Dosing Control Unit)
- SCR 2 strategy is in the Digital Diesel Electronics (DDE)
- Elimination of the reversing valve; two pumps are used instead
- Level sensors are contactless and operate on ultrasonic basis
- Pressure determination based on calculated pressure module, therefore the pressure sensor is no longer required
- Extraction connections were eliminated (became redundant due to the level sensor)
- Metering module is cooled by the engine cooling circuit
- Only one filler connection of the SCR system for active tank and passive tank (except F15 which has 2 different filling ports like E70)
- Encapsulated components without direct contact to the medium (avoids components damage due to contact with the corrosive DEF)



SCR Overview - Simplified

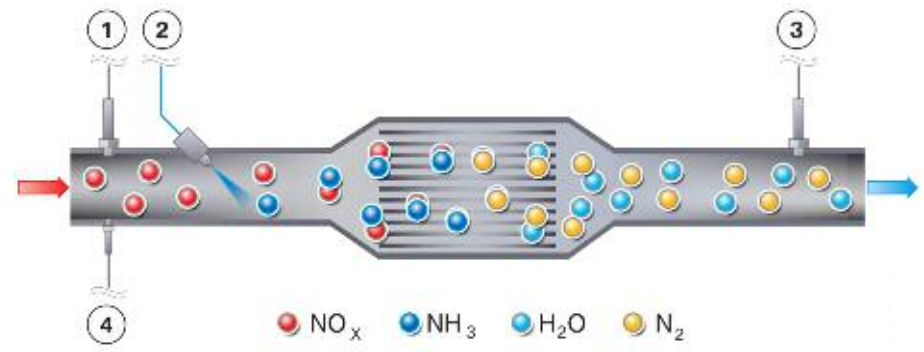
The Selective Catalytic Reduction (SCR) is currently the most effective system for the reduction of nitrogen oxides (NO_x). During its function it achieves an efficiency of almost 100% and over the entire vehicle operation about 90%. The difference can be found in the time that the system requires to be operational after a cold start.

The urea/water mixture (AdBlue®) is injected into the exhaust pipe via the metering module before the SCR catalytic converter. The Digital Engine Electronics (DDE) calculates how much has to be injected.

The nitrogen oxide content in the exhaust gas is calculated via the NO_x sensor before the SCR catalytic converter. Using this value the exact required amount of urea/water mixture (AdBlue®) is injected in order to completely reduce the nitrogen oxides.

In the exhaust pipe the urea/water mixture (AdBlue®) transforms into ammonia. The ammonia reacts in the SCR catalytic converter with the nitrogen oxides and nitrogen (N₂) and water (H₂O) are created. Behind the SCR catalytic converter there is a second NO_x sensor which monitors the function.

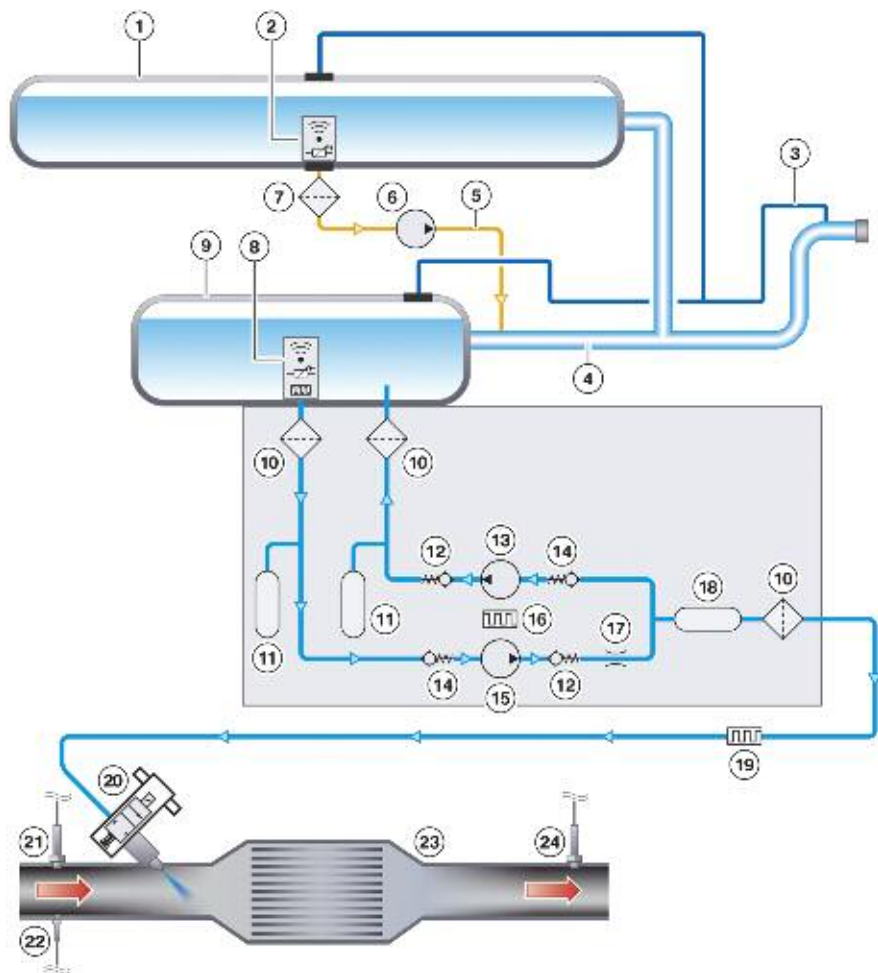
A temperature sensor in the exhaust pipe behind the diesel particulate filter (so before the SCR catalytic converter and the metering module) also influences the function. Because only once 170 °C is measured does the injection of the urea/water mixture (AdBlue®) begin.



Index	Explanation
1	NO _x sensor before the SCR catalytic converter
2	Metering module
3	NO _x sensor after the SCR catalytic converter
4	Temperature sensor after the diesel particulate filter

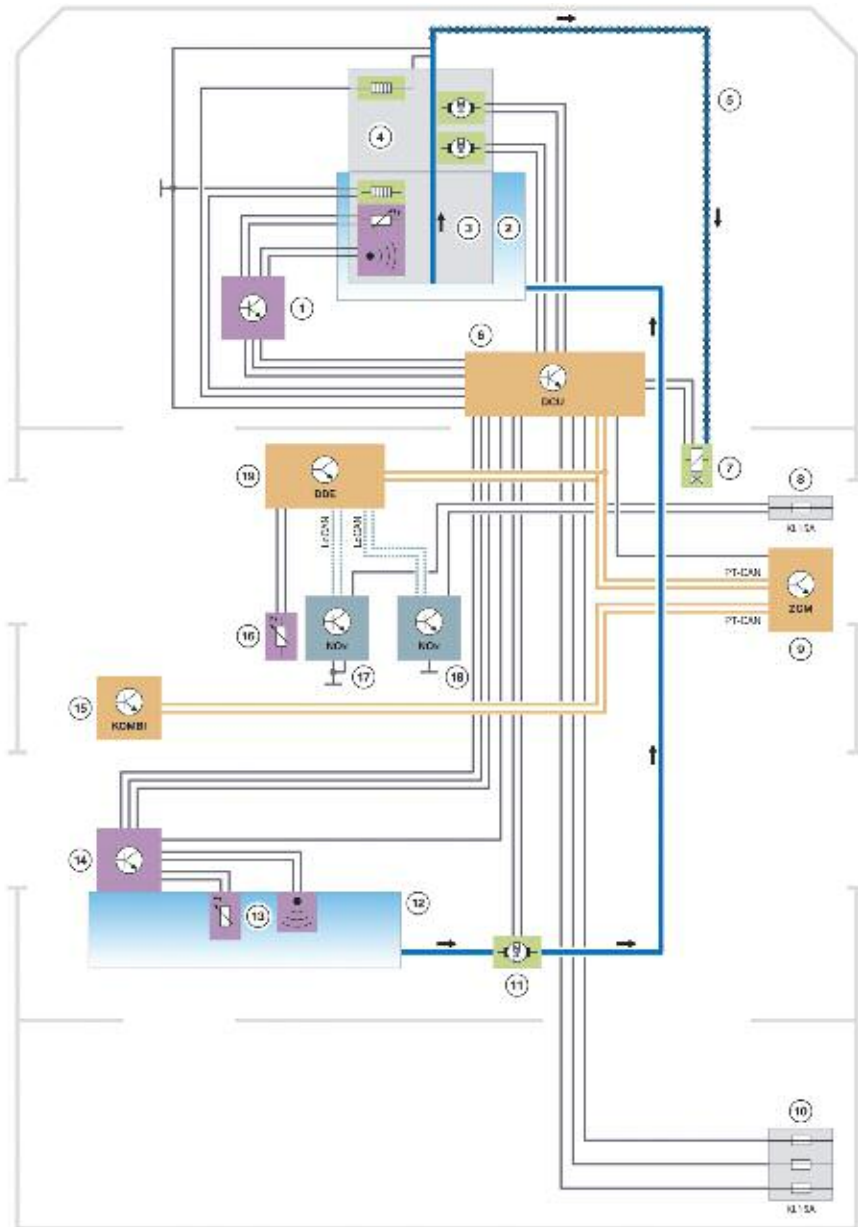
The chemical reaction that takes place in the SCR2 system is exactly the same as the first generation. See the previous SCR system training material for more information.

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



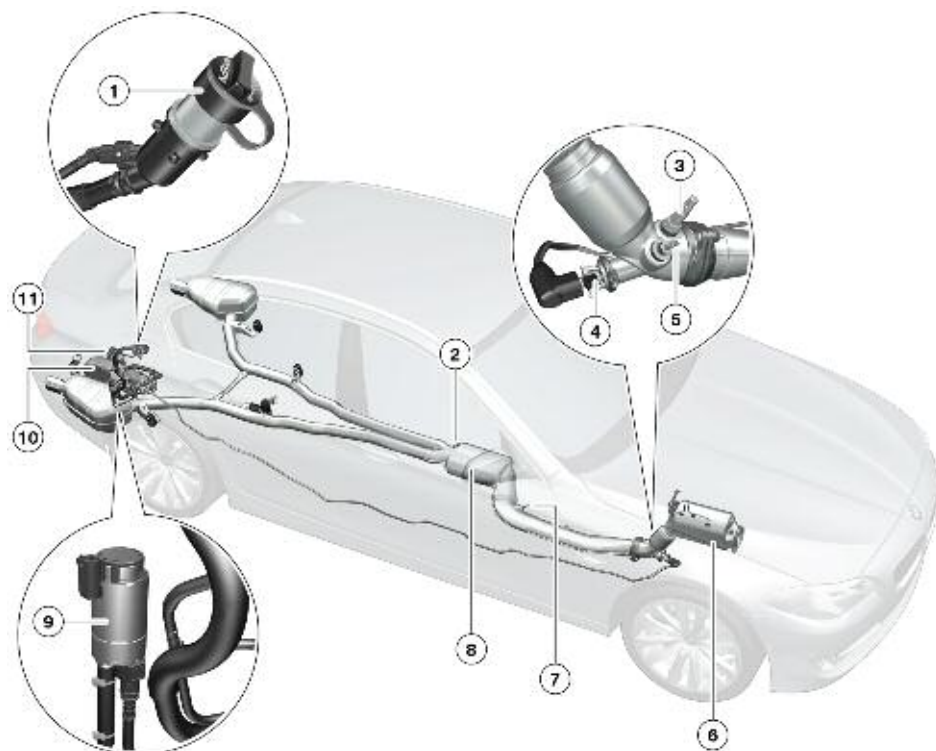
Index	Explanation
1	Passive tank
2	Tank flange, passive tank with level sensor and temperature sensor
3	Tank ventilation line
4	Fluid filler neck breather pipe
5	Transfer line
6	Transfer pump unit
7	Filter
8	Tank flange, active tank with SCR delivery module, level sensor, heating and temperature sensor
9	Active tank
10	Filter
11	Ice pressure damper
12	Fluid pressure control valve
13	Return pump
14	Intake valve
15	Fluid supply pump
16	Heating
17	Throttle
18	Pulsation damper
19	Heating metering line
20	Metering valve
21	NOx sensor before the SCR catalytic converter
22	Exhaust-gas temperature sensor after diesel particulate filter
23	SCR catalytic converter
24	NOx sensor after SCR catalytic converter

SCR system wiring diagram



Index	Explanation
1	Evaluation unit, active tank
2	Active tank
3	Level sensor, temperature sensor and heating, active tank
4	SCR delivery module with fluid supply pump, return pump and heating
5	Heating metering line
6	SCR dosing control unit (DCU)
7	Metering module
8	Fuse, supply of NOx sensors
9	Central gateway module (ZGM)
10	Fuses, supply of SCR dosing control unit
11	Transfer pump unit
12	Passive tank
13	Level sensor and temperature sensor, passive tank
14	Evaluation unit, passive tank
15	KOMBI (instrument cluster)
16	Exhaust-gas temperature sensor
17	NOx sensor before the SCR catalytic converter
18	NOx sensor after SCR catalytic converter
19	Digital Diesel Electronics (DDE)

SCR System Components



SCR component location - F10

Index	Explanation	Index	Explanation
1	Urea/water mixture AdBlue®, filler connection with fluid filler cap	7	Exhaust-gas temperature sensor after diesel particulate filter
2	NOx sensor after SCR catalytic converter	8	SCR catalytic converter
3	Oxygen sensor	9	Transfer pump unit
4	Metering module	10	Active tank
5	NOx sensor before the SCR catalytic converter	11	SCR dosing control unit (DCU)
6	NOx storage catalytic converter and diesel particulate filter		

Component Location

In the F10 with the N57D30O1 a 15 liter capacity active tank is installed, which is located in the vehicle underbody at the rear right. A passive tank is not installed in the US market F10. The filler connection for the urea/water mixture (AdBlue®) is located in the fuel filler flap beside the (diesel) fuel filler neck at the rear right of the vehicle.

In the F30 with the N47D20O1 an 8.7 liter capacity active tank is used, which is located in the vehicle underbody in front of the right rear wheel. The F30 passive tank is located behind the right rear wheel and has 9.4 liters. The filler connection for the urea/water mixture (AdBlue®) is located in the fuel filler flap beside the (diesel) fuel filler neck at the rear right of the vehicle.

The F31 has the same SCR system as F30 therefore the tanks have the same capacity and are installed in the same general locations.

In the F15 the active tank has a max volume of 13.7 liters and the passive tank has a 15.3 liter capacity. The active tank is located on the right side of the vehicle directly behind the front bumper cover. And the passive tank is located in the vehicle underbody in the area under the front seats. The filler connections for the urea/water mixture (AdBlue®) are located in the engine compartment. The passive tank filler point is at the same position as E70 (on the left side of the engine compartment).

The different tank sizes result from the available free installation areas in the different series.

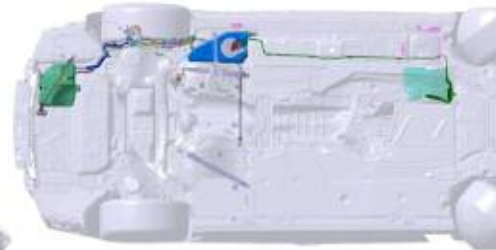
The installation location of the SCR dosing control unit (DCU) varies from series to series, whereby for the E70 with the first SCR generation the SCR control and strategy was still integrated in the Digital Diesel Electronics.

DEF dosing System of BMW 3 series:

Active tank below rear seat,
Passive tank below trunk.
One filling port for both tanks.



Bottom view without cover



Bottom view with cover

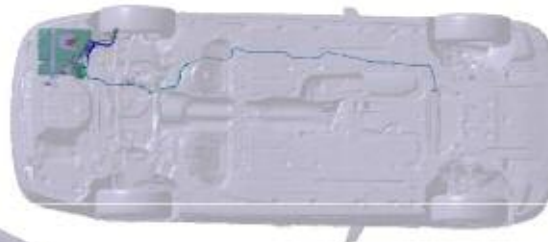


DEF dosing System of BMW 5 series:

Active tank below trunk,
Passive tank in the wheel arch.
One filling port for both tanks.



Bottom view without cover



Bottom view with cover



Passive Tank

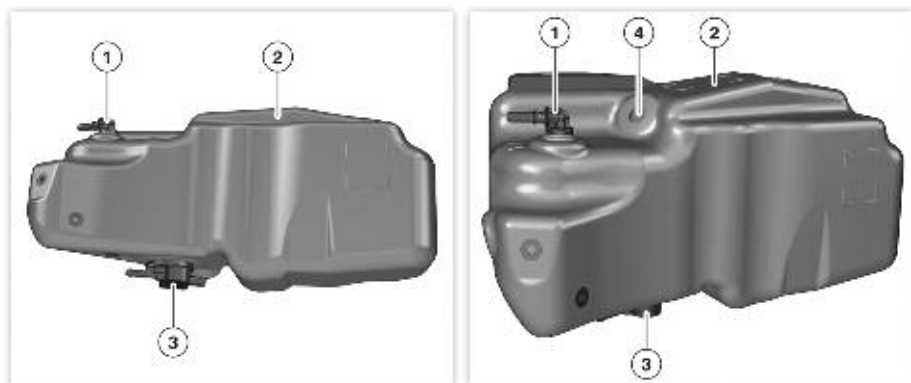
The name passive tank means that it is not heated.

The following components belong to the passive tank:

- Tank flange with level sensor and temperature sensor
- Filling port
- Service vent line, fluid filler neck breather

Depending on the series, it is possible that the passive tank is insulated. The insulation comprises foam material and prevents quick freezing at low temperatures.

Passive tank, two-tank system



Index	Explanation
1	Service vent line and fluid filler neck breather
2	Passive tank
3	Tank flange with level sensor and temperature sensor
4	Filling port

As its installation location may also be near the exhaust system depending on the vehicle, it would also lead to a high introduction of heat to the urea/water mixture (AdBlue®).

If there are very low temperatures over a long period of time there is a possibility that the urea/water mixture (AdBlue®) might completely freeze in the passive tank. No re-pumping can then take place. In this case the active tank must be refilled more often.

The passive tank cannot be filled separately on F30/F31, filled via the active tank. The DEF will flow to the active tank until this is full. Then the liquid will rise in the filler pipe and the passive tank will be filled. The F15 has a separate filler pipe for the passive tank.

Passive tank, two-tank system of the F30



Vehicle	Volume	Location	Position of filler neck
F10	-	Not installed	Next to fuel filler cap
F30/F31	9.4 liters	Vehicle underside, behind right wheel	Next to fuel filler cap
F15	15.3 liters	Vehicle underbody, under front seat area	In the engine compartment
F02	-	Not installed	On the rear bumper under the trunk lid

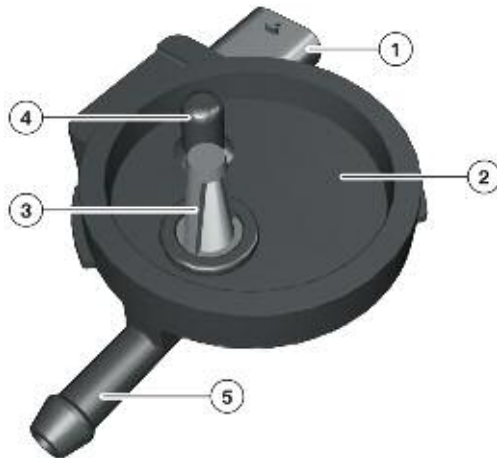
Level Sensors

A level sensor is located in the tank flange of the passive tank.

The sensor works with ultrasound.

On extreme sloping positions or if the tank is frozen, the signal is at 15 mm. This corresponds to the signal of an empty tank.

A level sensor is located, as described, in the active tank and in the passive tank.



Index	Explanation
1	Electrical connection
2	Flange with integrated temperature sensor
3	Strainer
4	Ultrasonic sensor fluid level
5	Transfer line connection

Tank flange in the passive tank

■ Venting

The passive tank has a service vent line and a fluid filler neck breather. The service vent line and fluid filler neck breather lead to the filling pipe for the urea/water mixture (AdBlue®) at the fluid filler cap.

■ Temperature Sensor

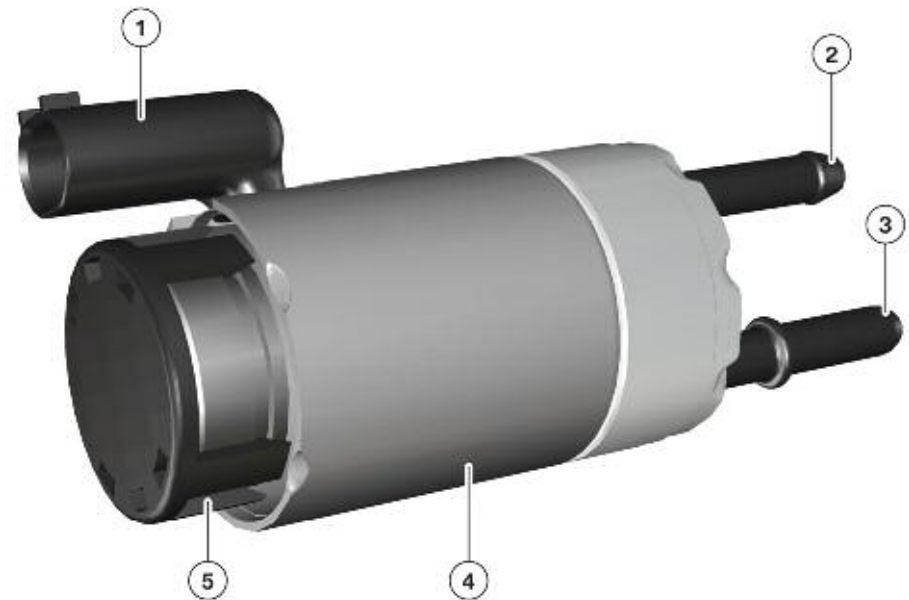
The temperature sensor is integrated in the tank flange and cannot be replaced separately. The temperature sensor integrated in the tank flange is installed in the active tank and the passive tank.

Transfer Pump Unit

The transfer pump unit assumes the delivery of the urea/water mixture (AdBlue®) from the passive tank to the active tank.

The transfer pump unit is only present if a two-tank system, i.e. passive tank and active tank, is installed.

The transfer pump unit is a membrane pump. It functions similarly to a piston pump, only that the pump element is separated from the medium via a diaphragm. This means there are no problems concerning corrosion.



Index	Explanation
1	Electrical connection
2	Intake side from transfer line passive tank
3	Pressure side to transfer line fluid filler neck breather pipe active tank
4	Pump body
5	Pump motor

Active Tank

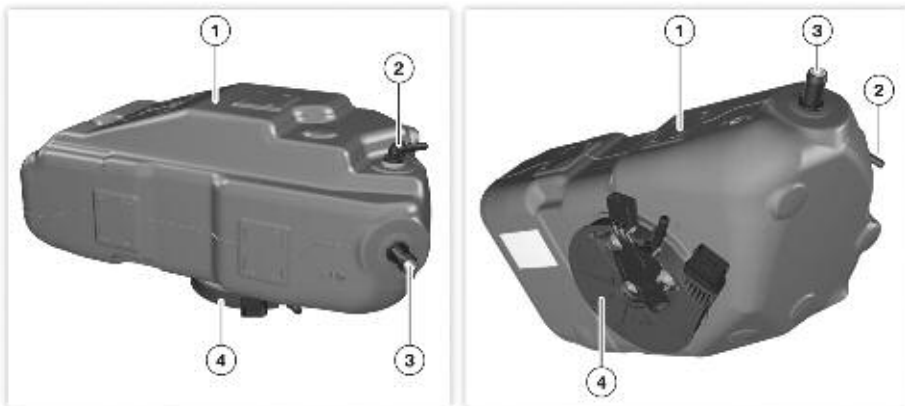
The active tank is so-called because it is heated.

The following components belong to the active tank:

- Level sensor
- Temperature sensor
- Service vent line, fluid filler neck breather
- Tank flange module with SCR delivery module and heating

Depending on the series, it is possible that the active tank is insulated. The insulation comprises foam material and prevents quick freezing at low temperatures. As its installation location may also be near the exhaust system depending on the vehicle, it would also lead to a high introduction of heat to the urea/water mixture (AdBlue®).

Active tank



Index	Explanation	Index	Explanation
1	Active tank	3	Filling port
2	Service vent line and fluid filler neck breather	4	Tank flange module

Possible danger as a result of incorrect refilling! Urea/water mixture (AdBlue®) filler necks are clearly marked as such. Nevertheless, there is a danger of incorrect refilling by third parties. Incorrectly refilled urea/water mixture (AdBlue®) systems (in particular with materials containing mineral oil) may be destroyed (gaskets).

Active tank, two-tank system of the F30

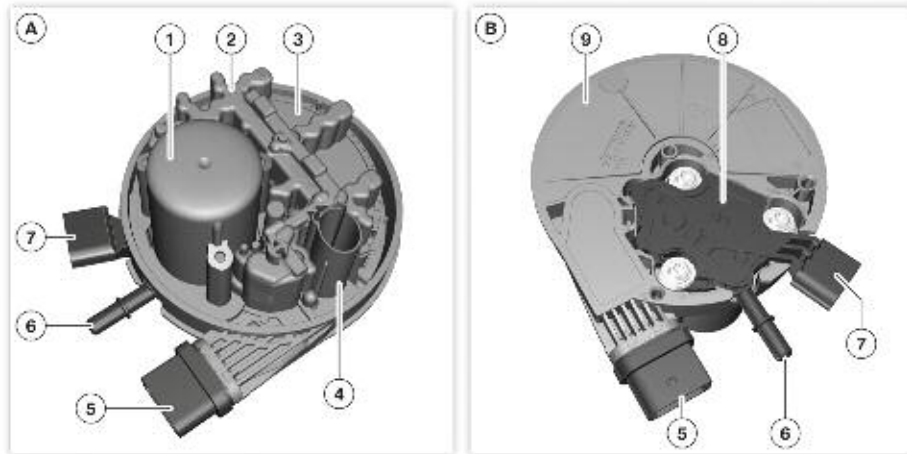


Vehicle	Volume	Location	Position of filler neck
F10	15 liters	Rear right between wheel arch and bumper	Next to fuel filler cap
F30/F31	8.7 liters	Rear right of the fuel tank, area below the right rear seat	Next to fuel filler cap
F15	13.5 liters	Front right between wheel arch and bumper	In the engine compartment
F02	15 liters	Rear right between wheel arch and bumper	On the rear bumper under the trunk lid

Tank Flange Module

The tank flange module is located in the active tank and holds the heating element, a filter, a temperature sensor and a level sensor. The tank flange module also holds the SCR delivery module. The tank flange module cannot be replaced individually in Service.

Tank flange module



Index	Explanation	Index	Explanation
A	Top view	5	Electrical connection for tank heating and evaluation unit for level and temperature
B	Bottom view	6	Metering line connection
1	Housing for SCR delivery module	7	Electrical connection for SCR delivery module
2	Heating element	8	SCR delivery module
3	Filter	9	Carrier plate
4	Housing for level sensor with integrated temperature sensor		

An electric auxiliary heater (positive temperature coefficient) is located in the tank flange module, so that at minimum temperatures liquid urea/water mixture (AdBlue®) is available for the journey.

The positive temperature coefficient elements can be regulated or switched off independently upon reaching a certain limit temperature. Intrinsic safety is thus guaranteed which prevents damage and destruction in the event of a fault with the continuous power supply.

The heating element in the tank flange module is supplied with electricity by a power semiconductor. The power semiconductor is controlled by the SCR dosing control unit (DCU). The SCR dosing control unit (DCU) can give out the electricity that flows via the heating elements and therefore monitor their function.

The temperature sensor delivers the signal for the control of the heating. It is an NTC sensor (negative temperature coefficient). The temperature sensor is integrated in the level sensor.

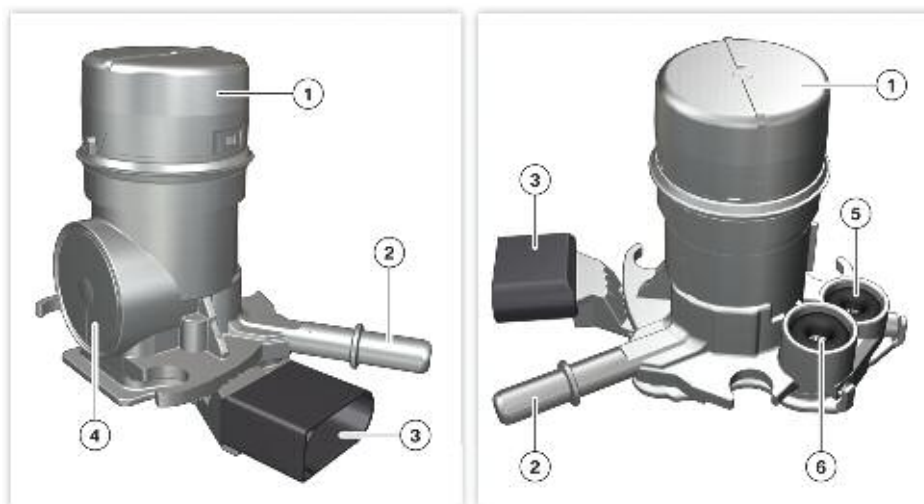
The level sensor in the tank flange module delivers the value of the level for the entire active tank.

The level sensor in the active tank works according to the same principle as the level sensor in the passive tank.

SCR Delivery Module

The SCR delivery module is integrated in the tank flange module (bolted on), which is located below at the active tank.

The SCR delivery module contains a supply pump and a return pump, maintenance-free filter, a throttle, two intake valves, two fluid pressure control valves for the supply pump and the return pump.



Index	Explanation	Index	Explanation
1	fluid supply pump	4	Return pump
2	Metering line connection	5	Pre-supply connection
3	Electrical connection	6	Return connection

The delivery pump sends the AdBlue to the SCR metering module. The delivery pump operates at a system pressure of between 4.5 and 8.5 bar. The return pump drains the pressure line. Partial draining of the pressure line is needed to avoid ice damaging the SCR metering module in freezing conditions. Although this is kept to a minimum due to acoustic reasons related to the refilling of the metering line.

In addition, the ice pressure dampers are housed in the supply lines (supply and return) for the active tank. These prevent damage to the SCR delivery module and its supply pump and return pump in the event of frozen and therefore enlarging urea/water mixture (AdBlue®).

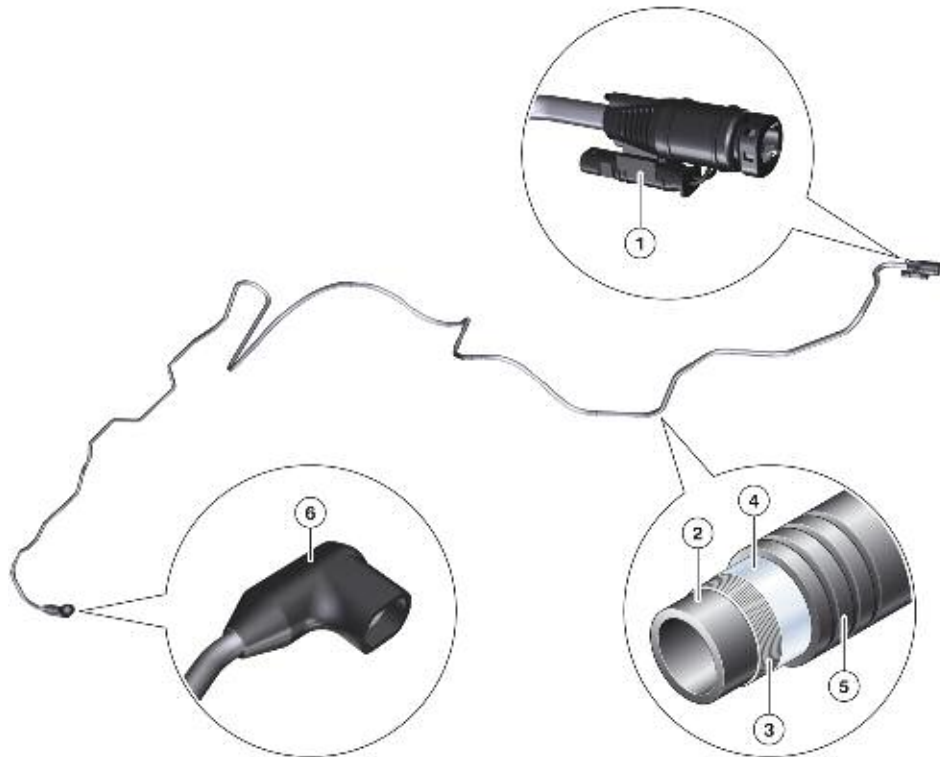
A pulsation damper and a strainer at the output for the metering line are also integrated in the SCR delivery module and prevent excessive pulsations in the metering line when the metering valve is open and penetration of dirt particles in the SCR delivery module (e.g. combustion residue, which could enter the SCR delivery module upon return of the urea/water mixture (AdBlue®) via the open metering valve.

The SCR delivery module also contains a heating element. The SCR delivery module heating comprises the copper conductor of the coils from supply pump and return pump.



The SCR delivery module can be replaced individually in Service.

Heated Metering Line



Similar to the heating in the tank flange module for the active tank or the pump in the SCR delivery module, the metering line is heated electrically, if required, in order to prevent the urea/water mixture (AdBlue®) freezing.

The metering line is a 4 x 1 pipe, i.e. a pipe with an outer diameter of 4 mm and an inner diameter of 2 mm with a wall thickness of 1 mm in which the urea/water mixture (AdBlue®) is transported to the delivery module.

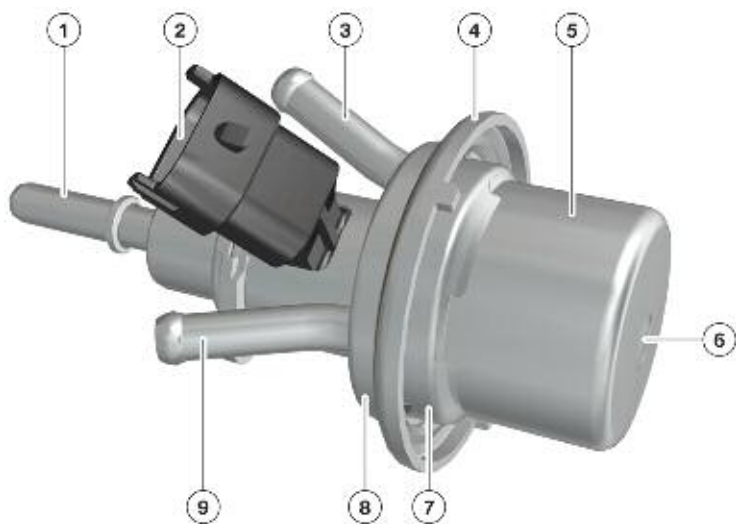
The heating element in the form of ohmic heating wires is attached from the outside to this 4 x 1 pipe, insulated and then physically protected by a corrugated plastic coating.

Index	Explanation
1	Connection for tank flange module (hydraulic connection of metering line - electrical connection of metering line heating)
2	Line, urea/water mixture (AdBlue®)
3	Heating coils
4	Insulator
5	Protective sleeve
6	Hydraulic connection for metering module

Metering Module and Mixer

As with the previous system the metering module ensures the injection of the urea/water mixture (AdBlue®) into the exhaust pipe. It includes a solenoid valve that is similar to the fuel injector of a gasoline engine.

The metering module is not heated, but is heated up by the exhaust system therefore it has to be cooled using coolant from the engine cooling system.

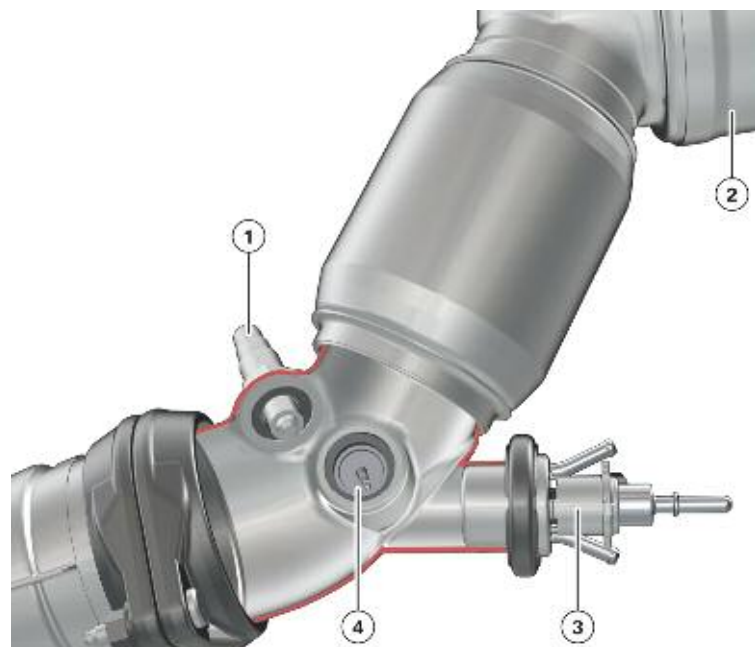


Metering module

Index	Explanation	Index	Explanation
1	Metering line connection	6	Metering port
2	Electrical connection, metering valve	7	Sealing ring groove
3	Coolant inlet	8	Heat sink
4	Mounting flange	9	Coolant return
5	Thermal protection		

The metering module is activated by a pulse-width-modulated (PWM) signal from the SCR dosing control unit (DCU) in which the duty cycle determines the opening duration of the valve.

A cone-shaped insert is attached at the metering module. This prevents the residue of the urea/water mixture (AdBlue®) drying up and the valve clogging. The shape creates a flow that prevents the urea/water mixture (AdBlue®) from sticking to the walls of the exhaust system. Deposits of urea on the insert are burnt off as it is heated by the exhaust flow.



Metering module installation location

Index	Explanation	Index	Explanation
1	Oxygen sensor	3	Metering module
2	Diesel particulate filter	4	NOx sensor before the SCR catalytic converter

■ Mixer

The mixer is located directly behind the metering module in the exhaust system. It is inserted in the flange joint of the exhaust pipe. It swirls the exhaust flow in order to achieve a better mix of the urea/water mixture (AdBlue®) and the exhaust gas. This is necessary so that the urea is fully transformed into ammonia. The mixer can be replaced individually in Service.

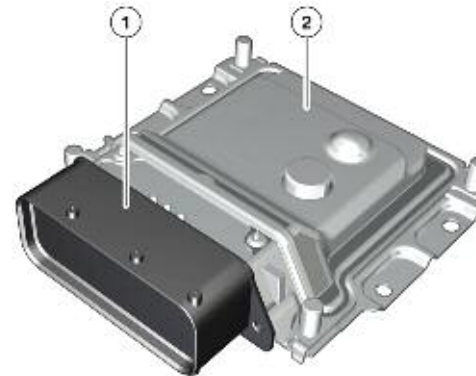


Index	Explanation	Index	Explanation
1	Mixer	3	Sealing in the flange
2	Mounting hole	4	Centering pin

SCR Dosing Control Unit (DCU)

The SCR dosing control unit (DCU) must ensure that the input variables for the metering specification of the Digital Diesel Electronics (DDE) are in the permissible range. The fluid levels of the urea/water mixture (AdBlue®) passive tank (no vehicle operation without reducer), the medium temperatures in the urea/water mixture (AdBlue®) passive tank and the metering line (AdBlue®, freezing point at -11 °C/12.2 °F) and the pressure build-up metering line (ensures fluid injection rate) are relevant here.

The SCR dosing control unit ensures that all available information is also available for other applications, for example the fluid level indicator and the remaining range (999 mls and 199 mls) display warning in the central information display (CID).



Index	Explanation
1	Connector
2	Control unit

Vehicle	Location
F10	Spare wheel well area
F30	On the right side in the trunk, near the manual emergency release of the fuel door
F31	On the right side in the trunk, near the manual emergency release of the fuel door
F15	Engine support, front right above SCR active tank



Please consult the respective repair information in ISTA for the current component installation locations.

NOx Sensors

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



The nitrogen oxide sensor can be compared in its operating principle with a broadband oxygen sensor. The measuring procedure is based on the idea to lead the nitrogen oxide measurement back to an oxygen measurement.

The exhaust gas flows through the NOx 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. See SCR 1 for a full Description of the operation of the NOx sensor.

As with the first generation two NOx sensors are installed, one upstream of the SCR catalyst and one downstream. Although these sensors are of the same type and use their own corresponding control units, they are different and cannot be interchanged.

For example; on the F30 the front NOx sensor is NGK NS11A-12E30B-B and the rear is NGK NS11A-12F04C-C. The front NOx sensor control unit is located to the left of the transmission and the rear NOx sensor control unit is on a bracket with the PM sensor's control unit to the left of the drive shaft, under heat shield.

NOTES
PAGE

SCR 2 Functions

SCR Control

The SCR control takes place in the SCR dosing control unit (DCU) and in the Digital Diesel Electronics (DDE).

The SCR control is divided into the dosing system control, which is implemented by the SCR dosing control unit (DCU), and the metering strategy, which is defined by the Digital Diesel Electronics (DDE).

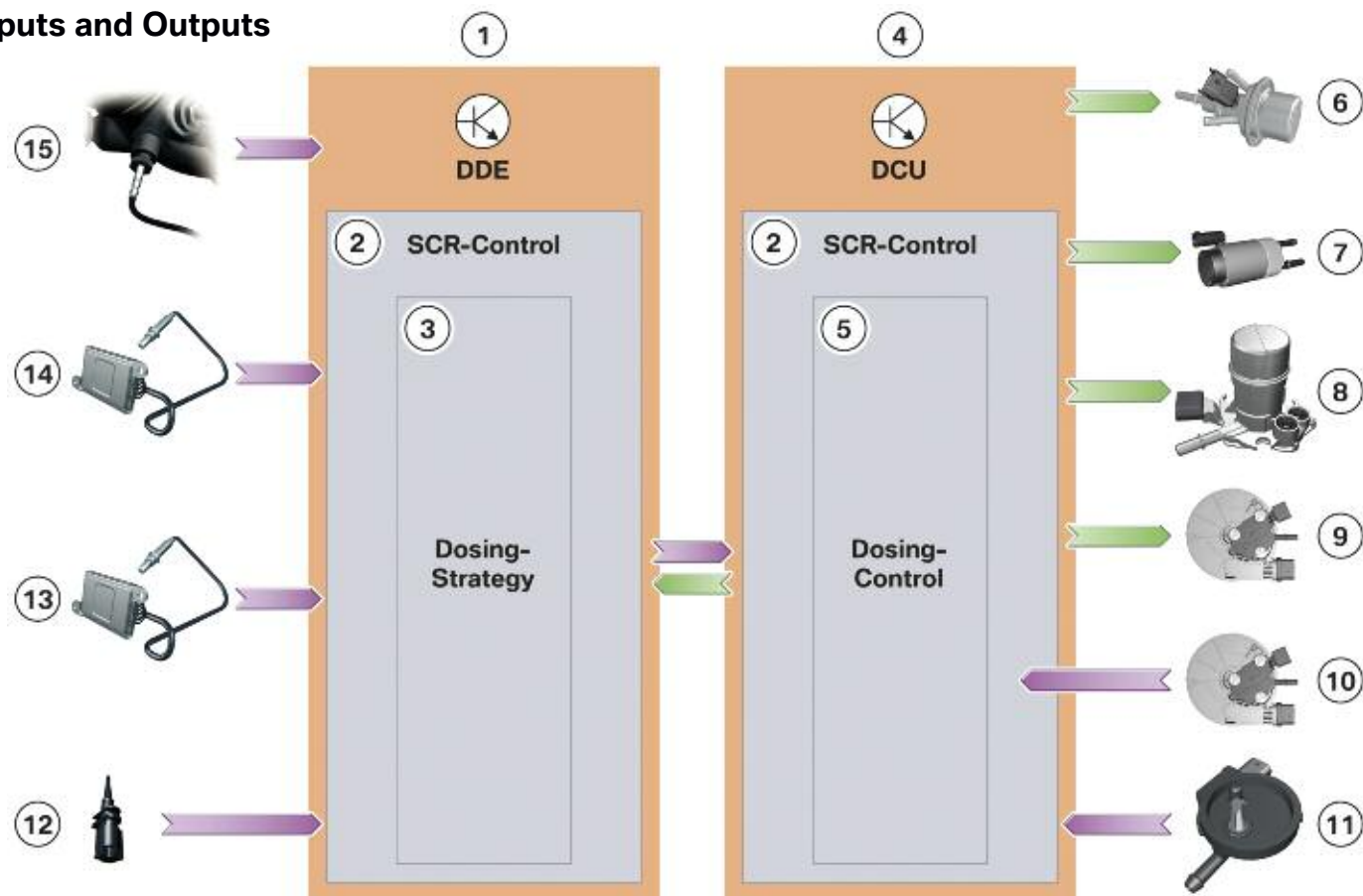
The SCR dosing control unit (DCU) assumes the following functions:

- System functions CAN communication and network management
- Control of the urea/water mixture (AdBlue®) pumps, metering line filling/emptying and pressure build-up/pressure reduction
- Control of the urea/water mixture (AdBlue®) metering module, implementation of the metering amount specification of the Digital Diesel Electronics (DDE)
- Control of the urea/water mixture (AdBlue®) heating
- Evaluation of the level sensors and temperature sensors
- Monitoring functions
- On-board diagnosis (OBD) monitoring
- Control of the heating in active tank, pump and metering line
- Control of the pumping function from passive tank (if installed) to active tank.

The Digital Diesel Electronics (DDE) assumes the following functions:

- Evaluation of the nitrogen oxide sensor
- Evaluation of the exhaust-gas temperature sensor
- Calculation of the urea/water mixture (AdBlue®) amount and transmission to the SCR dosing control unit (DCU) via PT-CAN
- Control of the switch off scenario.

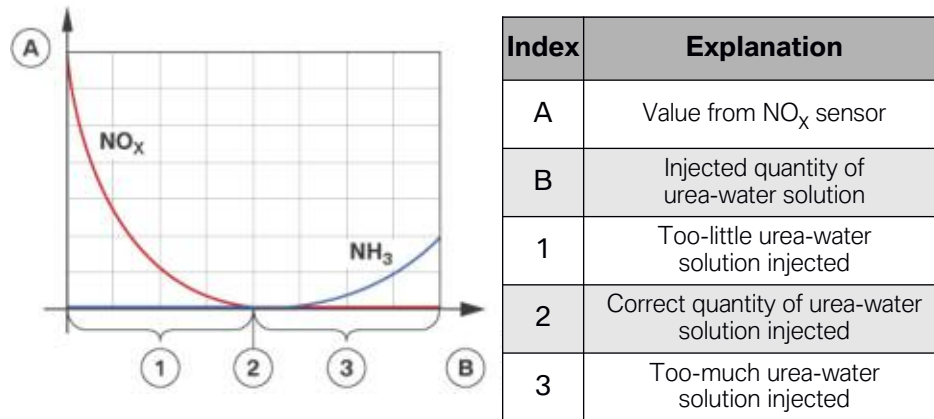
SCR Control Inputs and Outputs



Index	Explanation	Index	Explanation
1	Digital Diesel Electronics (DDE)	9	Tank flange, active tank with heating
2	SCR control	10	Level sensor and temperature sensor in tank flange, active tank
3	Metering strategy	11	Level sensor and temperature sensor in tank flange, passive tank
4	SCR Dosing Control Unit (DCU)	12	Outside temperature sensor
5	Dosing system control	13	NO _x sensor before the SCR catalytic converter
6	Metering module	14	NO _x sensor after SCR catalytic converter
7	Transfer pump unit	15	Exhaust-gas temperature sensor
8	SCR delivery module		

Metering Strategy

The metering strategy in the Digital Diesel Electronics (DDE) is the part of the SCR control that calculates how much urea/water mixture (AdBlue®) is injected at which time.



The signal of the NO_x sensor before the SCR catalytic converter is used for the calculation of the quantity in normal operation. This calculates the amount of nitrogen oxide in the exhaust gas and transmits the value to the Digital Diesel Electronics (DDE).

However, the NO_x sensor must reach its operating temperature in order to begin measuring. Depending on the ambient temperature this can take up to 15 min. Until this point a substitute value from the Digital Diesel Electronics (DDE) is calculated for the determination of the nitrogen oxide quantity in the exhaust gas.

In order to monitor the system there is a second NO_x sensor downstream of the SCR catalytic converter. It measures whether there are still nitrogen oxides in the exhaust gas.

If this is the case, then the fluid injection rate of the urea/water mixture (AdBlue®) is adapted. The NO_x sensor not only measures the nitrogen oxides, but also ammonia, but is unable to make a distinction between the two.

If too much urea/water mixture (AdBlue®) is injected, then the nitrogen oxides are fully reduced, however, there is an increased risk of a so-called "ammonia slip", i.e. ammonia escapes from the SCR catalytic converter. The value is increased as the NO_x sensor measures again. Therefore, the target is to reach a minimum of the sensor value.

However, this is a long-term adaptation and not a short-term control as the SCR catalytic converter has a memory function for ammonia.

Metering System Control

The metering system control in the SCR dosing control unit (DCU) is the part which performs the metering functions. It implements the requirements set by the metering strategy in the DDE.

This includes both the metering and the injection of the urea/water mixture (AdBlue®) as well as the supply of the urea/water mixture (AdBlue®).

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 after-running
- 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 establishes the quantity of the urea/water mixture (AdBlue®) that should be injected. The metering system control now ensures the implementation of this requirement.

The metering activation is a part of the function from which the actual opening of the metering valve is determined.

Depending on the load level of the engine and speed of the vehicle, the metering valve injects with a frequency of 0.3 Hz to 1.0 Hz.

The dosing valve is actuated with 0.3 Hz in Idle condition (for acoustic reasons) and at 0.9 Hz when a high dosing amount is requested.

In order to inject the right amount the metering control calculates following:

- The duty cycle for the actuator of the metering valve in order to ascertain the injection period
- Actuation delay to compensate for the reaction time of the metering valve.

The metering system control also calculates the actual metered amount and sends this back to the metering strategy.

The metering amount is also calculated over a longer period of time. This long period calculation is reset upon refilling.

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

An adequate supply of urea/water mixture (AdBlue®) is required for the proper operation of the Selective Catalytic Reduction (SCR) system. Furthermore, this medium must be stored in the vehicle and made available as quickly as it is necessary under all ambient conditions. In this case making available means that the urea/water mixture (AdBlue®) should be under a required pressure at the metering valve.

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

Heating

The SCR system must also be heated as the urea/water mixture (AdBlue®) freezes at a temperature of -11 °C (12.2 °F).

The heating function has the following tasks:

- Monitoring of the temperatures in the active tank and its surrounding area
- Thawing of a sufficient amount of urea/water mixture (AdBlue®) and the components required for metering at system start
- Prevention of freezing of the relevant components during operation
- Monitoring of the components of the heating system.

Following components are heated:

- Active tank
- Metering line (from the active tank to the metering module)
- SCR delivery module via the coils of the supply pump and return pump.

The heating of the active tank is adjusted depending on the temperature in the active tank and the ambient temperature. The required control of the heating for the metering line and the heating for the SCR delivery module are based on the current ambient temperature values.

Each heater circuit is supplied with power by a semiconductor switch (driver). These power semiconductors are designed as high side switches, which are switched directly by the control unit. With help of the shunt measuring principle, the SCR dosing control unit (DCU) calculates the actual current, which flows over the heating elements.

The DCU can also perform a function check of the heater circuits and thus detect any faults which are stored in the fault memory.

A temperature model is used for the heating of the components in order to establish the metering readiness.

With the temperature model, the following three basic parameters are set so that metering readiness can be reached.

The following values are defined by law and must be observed:

- at -25 °C (-13 °F) the metering readiness is reached after 45 minutes
- at -15 °C (5 °F) the metering readiness is reached after 20 minutes
- at -9 °C (15.8 °F) the metering readiness is reached after 3 minutes.

The following table shows the metering readiness in relation to the temperature:



Index	Explanation	Index	Explanation
t [min]	Delay time in minutes	°C	Temperature in degrees Celsius

At a temperature under -9 °C (15.8 °F) in the active tank the metering readiness is delayed, i.e. a defined time is waited until a pressure build-up begins. This time is constant from -9 °C to -15 °C (15.8 °F to 5 °F) as it cannot be ascertained at which degree the urea/water mixture (AdBlue®) is frozen. Under -15 °C (5 °F) the heating period extends until a pressure build-up attempt.

Generally heating up the metering line is significantly faster which is why the temperature in the active tank is decisive for the period until a pressure build-up attempt has been undertaken. If there is significantly lower ambient temperature than the temperature in the active tank the warm-up phase of the metering line becomes longer. Then the ambient temperature is used for the delay of the metering readiness.

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.

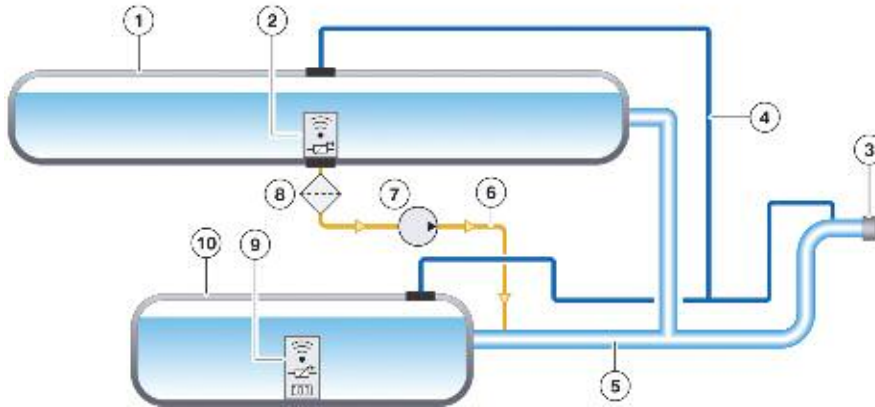
The delay time that is initiated by the temperature in the active reservoir is approximately 18 minutes while the delay time initiated by the ambient temperature is 25 minutes. Since the delay time initiated by the ambient temperature is longer, this will give rise to a longer delay.

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

As the storage of the urea/water mixture (AdBlue®) requires two tanks (which is series-specific) a transfer pumping system is required.



Index	Explanation	Index	Explanation
1	Passive tank	6	Transfer line
2	Temperature level sensor, passive tank	7	Transfer pump unit
3	Fluid filler cap	8	Filter
4	Tank ventilation line	9	Heating temperature sensor, level sensor, active tank
5	Fluid filler neck breather pipe, active tank — passive tank	10	Active tank

The delivery of urea/water mixture (AdBlue®) from the passive to the active tank is described as transfer pumping.

During transfer pumping the transfer pump unit pumps the urea/water mixture (AdBlue®) from the passive tank to the filling pipe. So that the filling pipe in the active tank is located below the filling pipe of the passive tank, the urea/water mixture (AdBlue®) does not return to the passive tank, but flows to the active tank.

The following preconditions must be met for transfer pumping:

- Urea/water mixture (AdBlue®) is present in the passive tank
- The ambient temperature is above a minimum value of -7 °C for at least ten minutes in the case of a longer engine switch-off time
- The ambient temperature is above a minimum value of -0 °C for at least ten minutes in the case of a shorter engine switch-off time
- An available volume of 300 grams is reached in the active tank
- Active tank and passive tank contain a liquid urea/water mixture (AdBlue®) (tank temperature below -5 °C).

Then enough time is spent re-pumping until the active tank is full again. If the level "full" is reached before this the transfer pumping is stopped.

If there is a fault in the fluid level sensor then there is no pumping.

Delivery

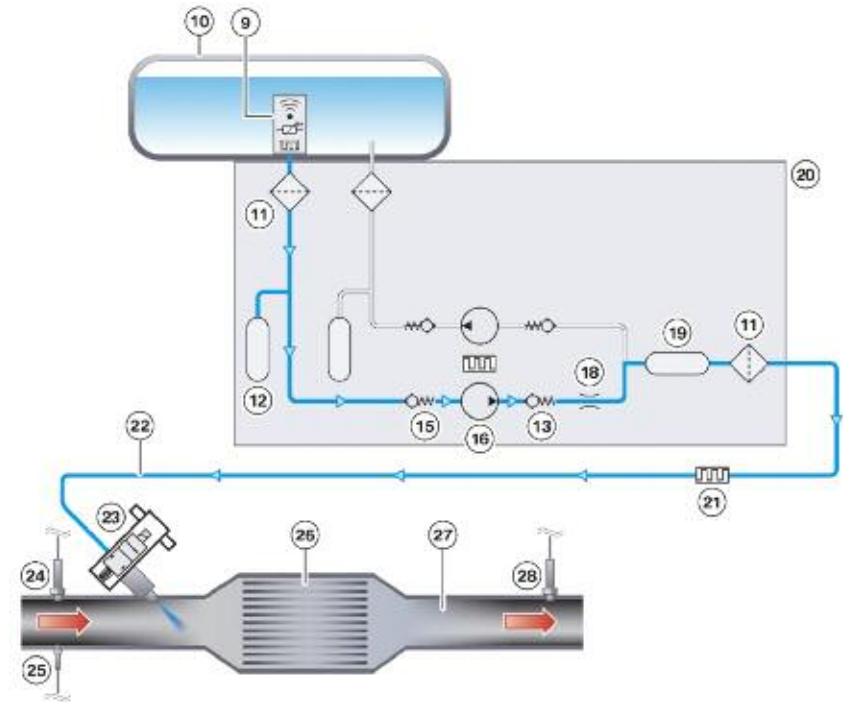
The urea/water mixture (AdBlue®) is delivered from the active tank to the metering module. The supply pump, which is located in the SCR delivery module, performs this task. The SCR delivery module requires the following components for this:

- Filter
- Intake valve
- Fluid supply pump
- Fluid pressure control valve
- Restrictor
- Pulsation damper
- Filter
- Metering line
- Heating, metering line, if required
- Metering valve.

The supply pump is activated via a pulse-width modulated signal (PWM signal) by the SCR dosing control unit (DCU). The PWM signal delivers a pump stroke specification so that the system pressure can be adjusted.

The PWM is used to limit the current for the DCU therefore the PWM is adjusted according to the actual voltage at the DCU. The pump is activated with a defined time in order to make a full stroke. The time is depending on the actual pressure in the system.

At the system start the supply pump is activated with a firm PWM signal to fill the line. The supply line is therefore filled until the metering module. Only then does the pressure build-up and regulation take place.



Index	Explanation	Index	Explanation
9	Heating temperature sensor, level sensor	20	SCR delivery module
10	Active tank	21	Heating metering line
11	Filter	22	Metering line
12	Ice pressure damper	23	Metering module
13	Fluid pressure control valve	24	NOx sensor before the SCR catalytic converter
15	Intake valve	25	Exhaust-gas temperature sensor after diesel particulate filter
16	Supply pump	26	SCR catalyst
18	Restrictor	27	Exhaust system
19	Pulsation damper	28	NOx sensor after SCR catalytic converter

When filling the metering line a small amount of the urea/water mixture (AdBlue®) is injected into the exhaust system as the metering valve is open.

During the pressure regulation, i.e. the normal operation with metering, the supply pump is activated in such a way that 6 bar of pressure is applied to the metering line. With the SCR 2 it is volumetric delivery, i.e. the volume of the urea/water mixture (AdBlue®) (which is made available by the supply pump) is actually injected at the metering valve.

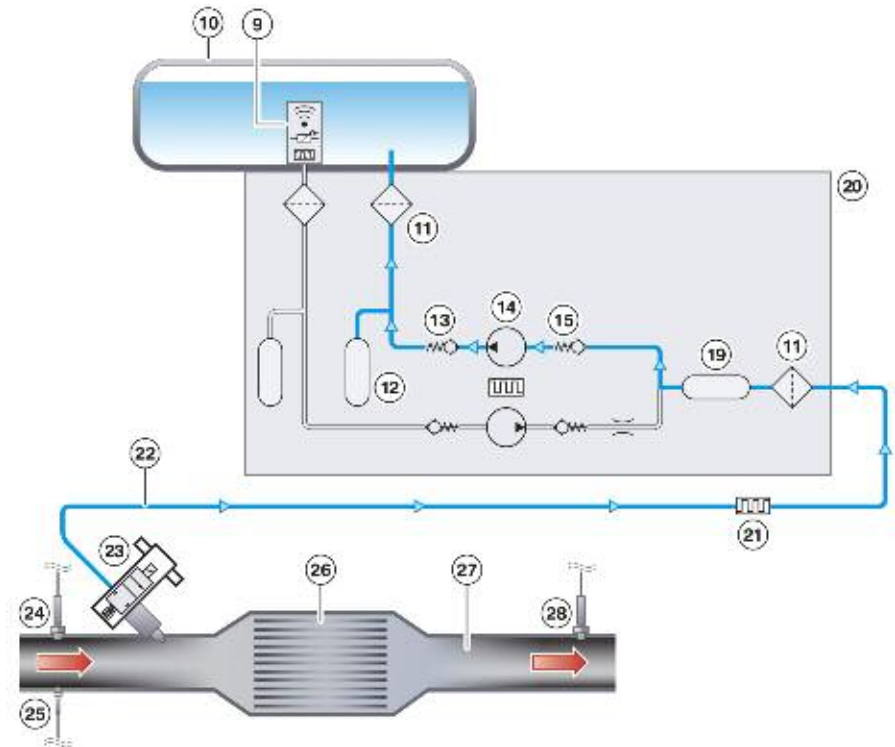
The quantity is determined by the opening period and opening stroke of the metering valve. However, this is so short that there is virtually no pressure drop in the metering line.

Evacuating

After the engine is stopped, the return pump of the SCR delivery module is activated and the metering line and the metering module are evacuated (drawn off).

The SCR delivery module requires the following components for this:

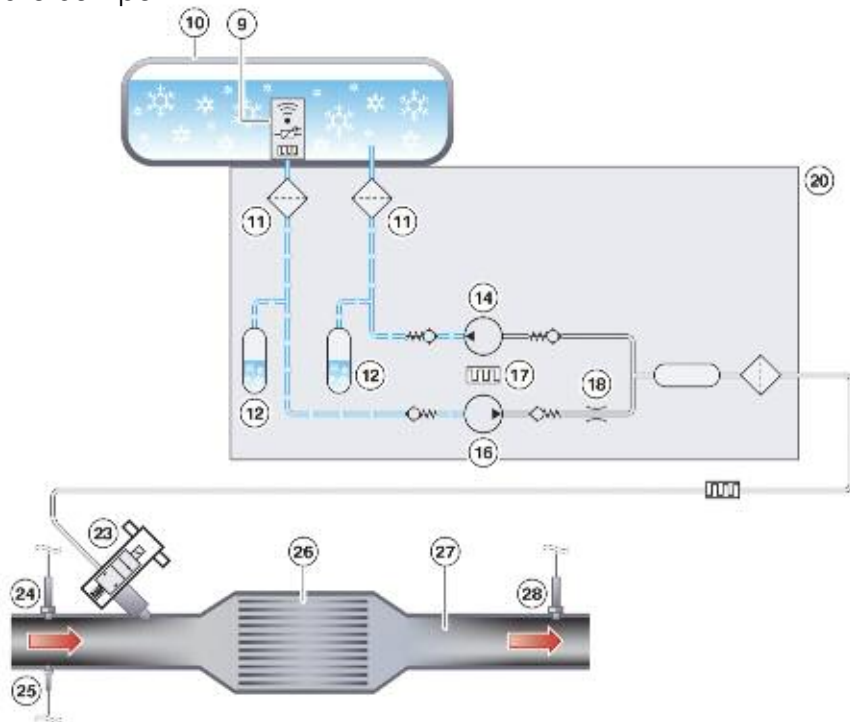
- Metering valve
- Heating, metering line, if required
- Metering line
- Filter
- Pulsation damper
- Intake valve
- Return pump
- Fluid pressure control valve
- Filter



Index	Explanation	Index	Explanation
9	Heating temperature sensor, level sensor in active tank	21	Heating metering line
10	Active tank	22	Metering line
11	Filter	23	Metering module
12	Ice pressure damper	24	NOx sensor before the SCR catalytic converter
13	Fluid pressure control valve	25	Exhaust-gas temperature sensor after diesel particulate filter
14	Return pump	26	SCR catalyst
15	Intake valve	27	Exhaust system
19	Pulsation damper	28	NOx sensor after SCR catalytic converter
20	SCR delivery module		

Freezing Conditions

If the ambient conditions cause the urea/water mixture (AdBlue®) to freeze, the SCR delivery module is protected by the ice pressure damper.



Index	Explanation	Index	Explanation
9	Heating temperature sensor, level sensor in active tank	20	SCR delivery module
10	Active tank	23	Metering module
11	Filter	24	NOx sensor before the SCR catalytic converter
12	Ice pressure damper	25	Exhaust-gas temperature sensor after diesel particulate filter
14	Return pump	26	SCR catalyst
16	Fluid supply pump	27	Exhaust system
17	Heating, pump	28	NOx sensor after SCR catalytic converter
18	Restrictor		

If the urea/water mixture (AdBlue®) freezes (below -11°C), the SCR delivery module and its components are protected by the ice pressure damper.

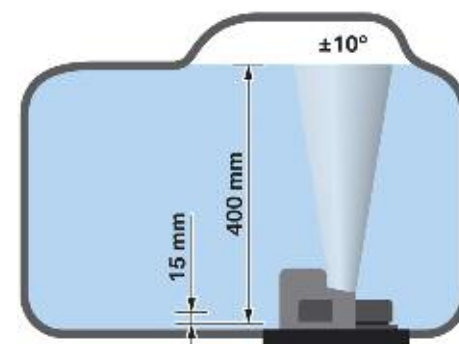
The ice pressure dampers allow an increased volume in the internal lines of the SCR delivery module thanks to their diaphragm, which is designed for the residual amount containing urea/water mixture (AdBlue®) in the SCR delivery module. The resulting increase in volume in the ice pressure dampers protects the internal components of the SCR delivery module by the ice formation.

Level Measurement and Temperature Measurement

There are level sensors and temperature sensors in the active tank and passive tank (if installed). These are ultrasonic sensors for the levels and can capture the levels in the range from 15 mm to 400 mm. The temperature sensors are embedded in the tank flange of the active tank and passive tank and work according to the negative temperature coefficient principle (NTC).

The signals of the level sensors and temperature sensors do not go directly to the SCR dosing control unit (DCU), but to an evaluation unit in the respective tank flange, as the SCR dosing control unit (DCU) cannot process the results of the ultrasonic sensors and temperature sensors directly.

In the evaluation unit the ultrasonic values and measured values of the temperature sensors are converted to a pulse-width modulated signal (PWM signal), which can be processed by the SCR dosing control unit (DCU).



Level measurement range of ultrasonic sensor

The pulse-width modulated signals (PWM signals) of level and temperature are transmitted in three pulse-width modulated signals of 120 ms units to the SCR dosing control unit (DCU). Another two pulse-width modulated signals of the evaluation unit are used for other purposes. The signal is implausible between 0 – 20 ms and 100 – 120 ms.

The PWM signal (pulse-width modulated signal) is broken down as follows:

T1: Temperature

- For the temperature measurement a PWM signal (pulse-width modulated signal) of 0% clock ratio = 20 ms of a temperature corresponds to urea/water mixture (AdBlue®) of -40° Celsius.
- For the temperature measurement a PWM signal (pulse-width modulated signal) of 50% clock ratio = 60 ms of a temperature corresponds to urea/water mixture (AdBlue®) of 20° Celsius.
- For the temperature measurement a PWM signal (pulse-width modulated signal) of 100% clock ratio = 100 ms of a temperature corresponds to urea/water mixture (AdBlue®) of 80° Celsius.

T2: 1st level measurement

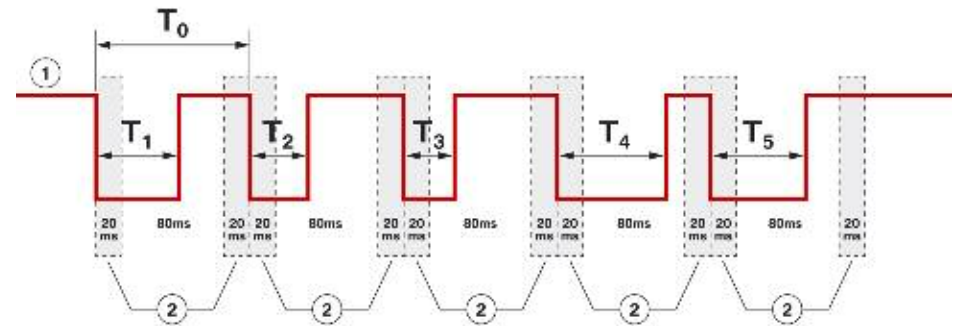
- For the first level measurement a PWM signal (pulse-width modulated signal) of 0% clock ratio = 20 ms corresponds to a level of urea/water mixture (AdBlue®) of 0%.
- For the first level measurement a PWM signal (pulse-width modulated signal) of 100% clock ratio = 100 ms corresponds to a level of urea/water mixture (AdBlue®) of 100%.
- The level range of 15 mm to 400 mm is transmitted in a total of 771 stages with a solution of 0.5 mm.

T3: currently not occupied

T4: 2nd level measurement

- Similar to T2, for the second level measurement a level is only recorded every 480 ms. The transmission is effected via the PWM signal (pulse-width modulated signal) in the 960 ms grid.

Therefore, two levels are transmitted per PWM signal (pulse-width modulated signal).

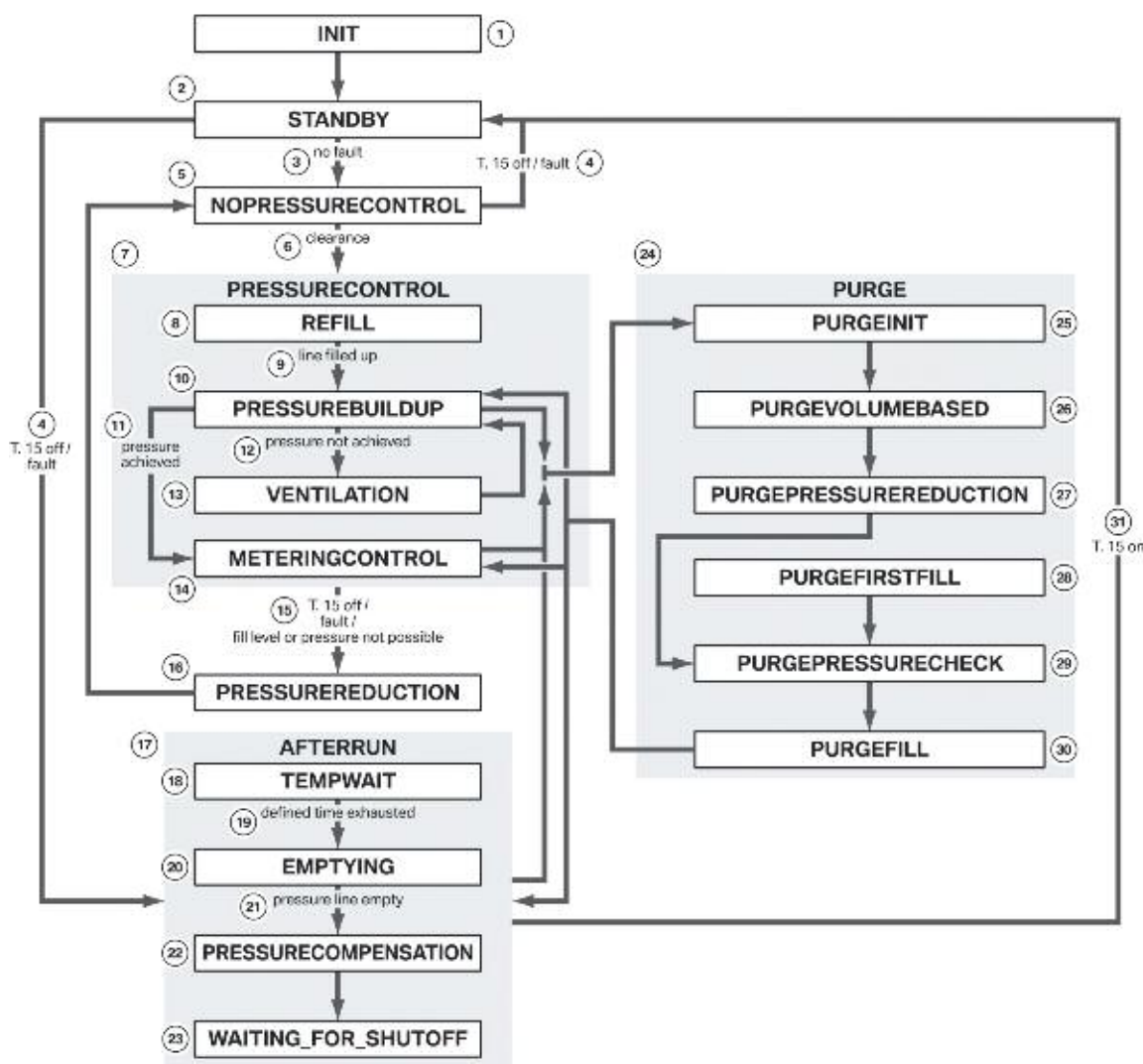


Index	Explanation
T ₀	Pulse width
1	Idling
2	Implausible range
T1-T5	Pulse-width modulated signal — clock ratio

SCR System Modes

If the ignition is switched on then the SCR control in the SCR control unit (DCU) runs through a logical sequence of conditions. However, there are preconditions that set off the change from one mode to the other.

The following graphic shows the system procedure of the modes/conditions:



Index	Explanation	Index	Explanation
1	Initialization	17	After-run
2	Standby (SCR not active)	18	Wait on temperature
3	No fault	19	Time frame lapsed
4	Terminal 15 Off/Fault	20	Drain
5	No pressure regulation/Wait on approval	21	Pressure line drained
6	Approval	22	Pressure compensation
7	Pressure regulation/SCR system running	23	Switch off
8	Filling	24	Purge
9	Line filled	25	Initialize purging
10	Pressure build-up	26	Purging, volume-based
11	Pressure reached	27	Purging, pressure reduction
12	Pressure not reached	28	Purging, initial filling
13	Ventilation	29	Purging, pressure test
14	Metering control/Metering	30	Purging, filling
15	Terminal 15 Off/Fault/Filling or pressure build-up not possible	31	Terminal 15 ON
16	Pressure reduction		

In comparison to the first generation SCR, there is an additional mode for the SCR 2: **PURGE MODE**

For the sake of clarification, all modes are described again in this training manual.

■ **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. AFTER RUN 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)**

NO PRESSURE CONTROL 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 NO PRESSURE CONTROL mode for a minimum period of time so that a plausibility check of the pressure sensor can be performed.

PRESSURE CONTROL mode is assumed once the enable is finally given. If terminal 15 is switched off in the NO PRESSURE CONTROL mode or a fault occurs, or the system should be reset (e.g. to improve metering accuracy or the pressure regulation), a switch is made to STANDBY mode.

■ **PRESSURE CONTROL (SCR system running)**

PRESSURE CONTROL mode is the normal operating status of the SCR system and has three sub-modes.

PRESSURE CONTROL mode is maintained until terminal 15 is switched off. Subsequently a change to PRESSURE REDUCTION mode then takes place. A change to PRESSURE REDUCTION mode also takes place if a fault occurs in the system.

The three sub-modes of PRESSURE CONTROL are described in the following:

• **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 (METERING CONTROL).

If the required pressure built-up is not achieved after the defined period of time has elapsed, or the condition unit goes into a slip, and VENTILATION mode is assumed.

If the pressure cannot be built up after a defined number of attempts, then the system indicates a fault and assumes PRESSURE REDUCTION mode.

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

• VENTILATION

VENTILATION is used for the ventilation of the pressure line and is performed for each PRESSURE BUILD UP.

From a certain pressure threshold in the PRESSURE BUILD UP mode, the metering valve is first activated for a certain time at a defined opening width. The pressure is compared before and after the valve opening. If the pressure drop is over a certain threshold value, the valve is activated again (this process can be repeated up to three or four times).

If the pressure drop is less than the threshold value, or the metering valve was activated four times, the VENTILATION mode is terminated and the system switches back to the PRESSURE BUILD UP mode.

The system can build up normal pressure with or without insufficient VENTILATION and switch to the METERING CONTROL mode. It may then transpire that upon the start of metering the system pressure collapses due to the escape of air. In this case the system changes to the PURGE mode and then to PRESSURE BUILD UP.

PRESSURE REDUCTION mode is assumed if terminal 15 is switched off during this time or a fault occurs in the system.

• METERING CONTROL

Upon entering PRESSURE REDUCTION the metering release is withdrawn.

This condition ensures a pressure reduction in the SCR delivery module, the metering line and the metering module after the PRESSURE CONTROL mode. In addition, the return pump is activated while the metering valve is closed.

The end of the PRESSURE REDUCTION mode is reached by dropping below a certain pressure.

■ “PURGE”

In the PURGE mode the system is purged. This has six modes.

The system switches to PURGE mode, if no pressure build-up is possible or there is a vacuum in the system. This condition may occur if, for example, air or a foreign body are in the system or valves are sticking. A switch to PURGE may also occur if the urea/water mixture (AdBlue®) in the SCR delivery module and the metering module is heated too much. Then in the PURGE mode the SCR delivery module and the metering line are purged with a certain amount of the urea/water mixture (AdBlue®) from the tank. Also a switch is made to the PURGE state, as soon as an initial operation is effected. This can happen both in the works during initial operation or may be necessary if components are replaced during servicing of the SCR system.

If the PURGE mode is exited, there is a switch to the initial mode before purging. This affects both the possible faults and the successful completion of the purging function. A reaction to the faults then takes place, if necessary, in the initial mode.

• “PURGE INIT” (initialization of purging function)

Based on the status of the initialization the transition to the required purging mode).

• “PURGE VOLUME BASED” (volume-based purging)

In the PURGE VOLUME BASED mode a defined volume of the urea/water mixture (AdBlue®) is pumped by the SCR delivery module.

• “PURGE PRESSURE REDUCTION” (pressure reduction during purging)

In the PURGE PRESSURE REDUCTION mode the pressure is reduced.

- **“PURGE FIRST FILL” (initial filling during purging)**

In the PURGE FIRST FILL mode the initial filling takes place. This mode can also be activated via the service functions in the diagnosis system (ISTA) and must be performed if components in the SCR system are replaced during servicing or upon the initial operation in the works.

- **“PURGE PRESSURE CHECK” (pressure build-up check during purging)**

In the PURGE PRESSURE CHECK mode a pressure build-up attempt is performed to check the initial filling. If this is unsuccessful, the PURGE FILL mode is exited for further filling (watch out for external leaks). This mode can also be activated via the service functions in the diagnosis system (ISTA) and must be performed if components in the SCR system are replaced during servicing or upon the initial operation in the works.

- **“PURGE FILL” (filling during purging)**

In the PURGE FILL mode the system is refilled. If the condition is exited successfully, a change to PURGE PRESSURE CHECK takes place for further checking.

- **“AFTER RUN” (after-run)**

In the AFTER RUN mode the system is shut down.

If terminal 15 is switched on again before the after-run has come to an end the after-run is considered interrupted and the condition switches to STANDBY. If this is not the case, the sub-modes of the AFTER RUN mode are run through.

- **“EMPTYING” (draining of the pressure line)**

After the cooling-down period it is switched to the sub-mode AFTER RUN EMPTYING. In this sub-mode the pressure line and the SCR delivery module are emptied.

The urea/water mixture (AdBlue®) is suctioned by the return pump and the opening of the metering valve back to the active tank. This should prevent the freezing of the urea/water mixture (AdBlue®) in the metering line or in the metering module.

If the pressure line is empty, a change to the AFTER RUN PRESSURE COMPENSATION mode is assumed.

It is also switched to the AFTER RUN PRESSURE COMPENSATION mode if there is a fault in the system. If terminal 15 is switched on it is switched to the STANDBY mode

- **“WAITING FOR SHUTOFF” (switching off SCR)**

The control unit is shut down and switched off.

Automatic Engine Start-stop Function

Under certain operating conditions an engine shutdown of the MSA may be influenced by the SCR control.

■ **Remaining Capacity Undershot**

If the remaining capacity falls below 0 km and there is no more urea/water mixture (AdBlue®) available, an automatic engine shutdown is prevented by the MSA. In the event of non-availability of the urea/water mixture (AdBlue®) in the area of the switch off scenario, an engine start is prevented (no engine operation without urea/water mixture (AdBlue®)).

Warning and switch off scenario

The SCR system is relevant for the exhaust-emission regulations. It thus fulfills an important emission requirement. If the system fails, the approval is void and the vehicle can no longer be operated. A very plausible case which leads to a system failure is that the supply of the urea/water mixture (AdBlue®) runs out.

Without urea/water mixture (AdBlue®) a further operation of the vehicle is not allowed, therefore the engine can no longer be started.

NOTE: The control of the switch off scenario is subject to the Digital Diesel Electronics (DDE).

So that it does not come as a surprise to the driver, there is a warning and switch off scenario that begins long enough before the disabling of the vehicle so that the driver can comfortably either refill the urea/water mixture (AdBlue®) themselves or have someone else refill it for them. According to legal regulations (in the US) the first warning must have a range of 1000 mls based on a linear counter (as E70 and E90).

Warning Scenario

■ Warning Level 1

At the start of the inducement (engine shut off scenario) a residual amount of DEF (about 3 liters in (F30) active tank, 3.2 liters for F10 and 3.5 liters in F15) should in any case be enough for a range of 1000 mls. The “linear counter” is started from this point irrespective of the actual DEF consumption. The driver receives a priority 1 Check Control message (white), with a check control message showing the remaining range. A range of 999 mls is actually displayed to provide a safety reserve margin.



Check Control message in the instrument cluster at warning level 1

Check Control display:

“Refill Exhaust Fluid Reserve/AdBlue, range: 999 mls”

At the same time, an instruction is also output via the central information display (CID):

“AdBlue reserve. AdBlue must be refilled. Have vehicle checked by your BMW Service Department.”

■ Warning Level 2

If the fluid level sensor has dropped below “empty” then the driver receives a priority 2 Check Control message (yellow). “Refill DEF” and the remaining range is displayed in mls. Although there is still a DEF reserve in the active tank (which would normally allow a range greater than 200 mls) a range of 199 mls is actually displayed to provide a safety reserve margin.

Check Control display: “Refill Exhaust Fluid Reserve/AdBlue, range: 199 mls”



Check Control message in the instrument cluster at warning level 2

At the same time, an instruction is also displayed via the Central Information Display (CID):

“Refill Exhaust Fluid/AdBlue”

“Note range. Exhaust Fluid/AdBlue must be refilled, otherwise an engine start is no longer possible. Drive to the nearest BMW Service Department.”

From this point onwards, the available range is counted downwards linearly, irrespective of actual urea/water mixture (AdBlue®) consumption.

■ Warning Level 3

If the range falls to 0 mls three lines are displayed instead of the range – next to the fluid gauge.



Check Control message in the instrument cluster range = 0 mls

Check Control display:

“Refill Exhaust Fluid/AdBlue, range: — — —”

At the same time, an instruction is also displayed via the central information display (CID):

“Refill Exhaust Fluid/ AdBlue.”

“Engine start without Exhaust Fluid/AdBlue no longer possible. Exhaust Fluid/AdBlue must be refilled. Drive to the nearest BMW Service Department.”

■ Switch OFF Scenario

When the range of 0 mls has been met the next engine start is prevented, **but only if the engine was switched off for more than three minutes.** This ensures being able to escape any dangerous situations.

There is normally a remaining 0.8 l in the system which is used as a safety reserve for the following scenario:

- The vehicle is filled up with fluid and is started with a very low urea/water mixture (AdBlue®) range (e.g. 1 km). The urea/water mixture (AdBlue®) range reaches 0 km/ml but the vehicle can still be driven until the next engine shut down. Here it is ensured that the vehicle is still operated with a functioning SCR system, even in this case.

■ Incorrect Refilling

If the wrong medium was filled, this becomes evident several hundred miles later in the increasing nitrogen oxide values in the exhaust gas despite the sufficient injection of the supposed urea/water mixture (AdBlue®). If certain limit values are exceeded, the system identifies a wrong medium. From this point this is displayed by a Check Control display (display of range or a reduction of range is not displayed).



Check Control message in the instrument cluster in the event the wrong medium is detected

Check Control display:

“Exhaust Fluid/AdBlue wrong medium”

At the same time, an instruction is also displayed via the central information display (CID):

“Exhaust Fluid/AdBlue wrong fluid”

“Have vehicle checked by your BMW Service authorized workshop.”

■ System Fault

Faults, which prevent the metering of the urea/water mixture (AdBlue®), or in the event of a communication failure between the Digital Diesel Electronics DDE and the SCR control unit (DCU), are shown by a Check Control display (display of the range or a reduction of the range is not displayed).



Check Control message in the instrument cluster in the event of system fault.

Check Control display: **“AdBlue system”**

At the same time, an instruction is also output via the central information display (CID):

“AdBlue system faulty.”

“Have system checked by your BMW Service Department.”

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:

- 10000 mls on the F30,
- 10000 mls on the F10 and F15,
- 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.

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Service Information

Refilling the System

The SCR system is generally maintenance-free. The service requirements are solely limited to refilling the urea/water mixture (AdBlue®).

The refilling of active and passive tanks with urea/water mixture (AdBlue®) can either be carried out in Service or by the customer themselves.

Refilling on an incline of up to 5° in any direction is no problem. 90% of the maximum possible refilling is still achieved.

The volume of the urea/water mixture (AdBlue®) tank is set out in such a way that a large range is possible. This means that the "normal" refilling takes place in a relatively long cycle so that the refilling can ideally take place in a second Service.

Should the urea/water mixture (AdBlue®) reserve not last until the next workshop visit a certain amount can also be refilled. A special bottle can be used for this that is screwed onto the fluid filler neck. The special bottle, also known as the "KRUSE bottle", guarantees filling without the danger of overfilling, overflowing or spraying in the engine compartment or on the paint surface.

Refilling using the KRUSE bottle is also possible via the urea/water mixture (AdBlue®) filler connection in the fuel filler flap as this bottle also runs dry at an angle of about 30°.

KRUSE refill bottles with a content of 0.5 US gallons can be ordered from the Electronic Parts Catalog (the current part numbers are set out in the Electronic Parts Catalog).



In the US the oil service target is now 10,000 mls. Therefore the oil service check control should appear before the DEF empty warning.

Should the starting of the engine already be prevented by the switch off scenario, one bottle is enough to get the engine to start again. Ideally two bottles should be used to stop the switch off scenario from occurring again straight away.



Special KRUSE bottles for urea/water mixture (AdBlue®)

Refilling in Service

For refilling in Service 10 liter canisters are available, which are used in conjunction with a special tool (the current special tool part numbers are set out in the Aftersales Assistance Portal).

Once the system is fully drained two canisters are required. Via the workshop system ISTA it can be checked whether both tanks, active tank and passive tank, were filled completely.

Refill canisters with a content of 10 liters can be ordered from the Electronic Parts Catalog (the current part numbers are set out in the Electronic Parts Catalog).

10 liter canister for urea/water mixture (AdBlue®)



Never refill the system from the canister without the special tools!

Damage to components may occur due to overfilling and spillage (especially in the engine compartment) where various materials are very sensitive to the corrosive properties of the urea/water mixture AdBlue®).

Urea/Water Mixture (AdBlue®) Fluid Filler Cap

The urea/water mixture (AdBlue®) fluid filler cap includes ventilation.

This ventilation is necessary as both the filling of the SCR system and the ventilation are realized via a common fluid filler neck breather pipe and tank ventilation line.



Index	Explanation
1	Urea/water mixture (AdBlue®) fluid filler cap
2	Handle
3	Ventilation

The ventilation is achieved via a defined bore hole in the urea/water mixture (AdBlue®) fluid filler cap. Therefore, only fluid filler caps which are approved for the respective vehicle are used.

A replacement or use of other fluid filler caps may cause a malfunction of the SCR system.

Checking the Urea/Water Mixture (AdBlue®) Concentrate

The quality check of the urea/water mixture (AdBlue®) is performed using a refractometer, which determines the urea concentration (the current special tool part numbers are set out in the Aftersales Assistance Portal). Using the enclosed pipette a drop of the medium to be tested is placed on the prism and the lid closed. The values are shown on the relevant scale using the light/dark boundary in the eyepiece.

Refractometer



Index	Explanation
1	Refractometer
2	Scales (battery acid density/coolant frost protection/urea/water mixture (AdBlue®))

Evaluation of the urea/water mixture (AdBlue®) concentrate:

- At values lower than 31.8 percent by weight, proper functioning of the urea/water mixture (AdBlue®) can no longer be guaranteed. Therefore, this must be replaced (for example, urea/water mixture (AdBlue®) aged by UV irradiation).

- The values are within the tolerance for values displayed between 31.8 and 33.3 percent in weight.
- Values higher than 33.3 percent in weight indicate a leak in the SCR system (for example if a proportion of water in the urea/water mixture (AdBlue®) has evaporated).

CAUTION!!!

Urea/water mixture (AdBlue®) which has been drawn off cannot be reused without a check. Long storage times and the influence of high temperatures and UV light have a subtle effect on the decomposition of the urea/water mixture (AdBlue®).

Evacuating the Urea/Water Mixture (AdBlue®)

If it is necessary to draw off the urea/water mixture (AdBlue®) within the framework of maintenance measures or repair measures or in the case of a excessive aging, this must be done using suitable tools.

There is no provision for draining the SCR system. See ISTA for the appropriate repair instructions and follow the procedure. The safety data sheet must be observed for handling and disposal.

CAUTION!!!

The drawn-off urea/water mixture (AdBlue®) must be collected in a suitable plastic tank. The pump must be purged with water after each use and cleaned.

Diesel Exhaust Fluid

The diesel exhaust fluid (DEF) is a urea-water solution which acts as the carrier for the ammonia that is used to reduce the nitrogen oxides (NOx) in the exhaust gas. In order to protect people and the environment against ammonia and in order to make it more manageable for transportation and tank processes it is available in a liquid urea for the SCR procedure.

The recommended urea/water mixture is AdBlue®. The naming rights of AdBlue® are owned by VDA (German Association of the Automotive Industry). AdBlue® 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.

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

■ Health and Safety

The urea/water mixture (AdBlue®) is not poisonous. 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.

If, when handling the urea/water mixture (AdBlue®), traces of the product come into contact with the skin, it is sufficient to wash it off with lots of water. An impairment of human health in this way is practically impossible.

■ 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. SCR components are incompatible with materials with a mineral oil base. In the event of uncertainties whether SCR system components came into contact with materials with a mineral oil base or SCR system components were filled with materials with a mineral oil base, there are test strips available to check the rest of the materials with a mineral oil base in the urea/water mixture (AdBlue®).

■ 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.

OBD Monitored Functions

The Digital Diesel Electronics (DDE) additionally has the task of monitoring all exhaust-relevant systems for their problem-free function. This task is described as an On-Board Diagnosis (OBD). If a fault is registered by the On-Board Diagnosis then the emissions warning light is activated.

The events specific to US diesel engines that cause the MIL to light up are described in the following:

SCR Catalytic Converter

The effectiveness of the SCR catalytic converter is monitored by the two nitrogen oxide sensors.

The nitrogen oxide mass is measured before and after the SCR catalytic converter and a sum is formed over a certain period. The actual reduction is compared to a calculated value which is stored in the Digital Diesel Electronics (DDE).

For this the following preconditions must be met:

- NOx sensors plausible
- Metering active
- Ambient temperature in the defined area
- Ambient pressure in the defined area
- Diesel particulate filter regeneration not active

- SCR catalytic converter temperature in the defined area (is calculated using exhaust-gas temperature sensor before the SCR catalytic converter amongst others)
- Exhaust flow in the defined area.

Monitoring includes four measuring cycles. If the actual value is lower than the one calculated a reversible fault is created. If the fault is determined in two driving cycles following one another then an irreversible (hard) fault is stored and the emissions warning light is activated.

In order to guarantee the SCR catalytic converter over a long period there is a long-term adaptation in which the metered amount is adjusted to the urea/water mixture (AdBlue®).

In order to undertake the adaptation the signal of the NOx sensor after the SCR catalytic converter is compared with a calculated value. If deviations occur here then the metering amount is adjusted in the short-term. The systematics of the adaptations is evaluated and a correction factor is applied to the metering amount.

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

If the correction factor exceeds a certain threshold a reversible fault is created. If the fault is determined in three consecutive driving cycles then an irreversible (hard) fault is stored and the emissions warning light is activated.

Supplying Urea/Water Solution (AdBlue®)

For a problem-free operation of the SCR catalytic converter the supply of urea/water mixture (AdBlue®) is necessary.

After the SCR catalytic converter reaches a certain temperature (calculated by the exhaust-gas temperature sensor in front of the SCR catalytic converter, amongst other things) the metering control tries a pressure build-up in the metering line. For this the metering module must be closed and the supply pump must be activated with a certain number of pump strokes for a certain amount of time.

If the pressure threshold cannot be reached within a certain amount of time then the metering module is opened in order to bleed the metering line. Subsequently a renewed pressure build-up is attempted.

If a set number of pressure build-up attempts take place unsuccessfully then a reversible fault is created. If the fault is determined in two driving cycles following one another then an irreversible (hard) fault is stored and the emissions warning light is activated.

This monitoring only runs once per driving cycle before the metering begins. If this monitoring is "passed" then the continuous pressure monitoring begins.

For the Selective Catalytic Reduction (SCR) a constant pressure of the urea/water mixture (AdBlue®) is necessary (6 bar). The actual pressure and the resulting pressure module are determined and monitored by the SCR dosing control unit (DCU) using an available parameter. The available parameter is the power consumption in a defined period of the supply pump in the SCR delivery module.

The following values are checked:

- High pressure
- Vacuum
- Implausible pressure readings.
- If these limits are exceeded for a certain amount of time a reversible fault is created. If the fault is determined in three consecutive driving cycles then an irreversible fault is stored and the emissions warning light is activated, the pressure in the SCR system is reduced fully and the SCR system shut down.

This monitoring takes place in active metering.

Level Measurement in Active Tank

A level sensor with ultrasonic technology is used for the active tank. The plausibility of the sensor takes place in the evaluation unit in which it is checked if the signals are logical.

In this case the evaluation unit sends a plausibility fault via the SCR dosing control unit (DCU) to the Digital Diesel Electronics (DDE). This takes place via a duty cycle of 30% of the PWM signal (pulse-width modulated signal). A reversible fault is created. If the fault is determined in two driving cycles following one another then an irreversible fault is stored and the emissions warning light is activated.

This monitoring only takes place if the temperature in the active tank is above a certain value.

If the line between the evaluation unit and at least one contact of the level sensor is broken then the fault is transmitted via a PWM signal (pulse-width modulated signal) with 40% clock ratio to the Digital Diesel Electronics (DDE). A reversible fault is created. If the fault is determined in three consecutive driving cycles (one after another) then an irreversible (hard) fault is stored and the emissions warning light is activated.

Suitable Urea/Water Solution (AdBlue®)

The SCR system is monitored with a wrong medium in terms of refilling. This monitoring begins when refilling is identified. The refilling identification is described in the previous SCR system training material.

In order to recognize a wrong medium the monitoring of the effectiveness of the SCR catalytic converter is used. If the effectiveness falls below a certain value with a set time after an identified refilling then a wrong medium is identified. In this case a reversible fault is created. If the fault is determined in two driving cycles following one another then an irreversible fault is stored and the emissions warning light is activated.

NOx Sensors

For the operation and therefore also the monitoring of the NOx sensor a so-called dew point must be reached. This ensures that no more water is in the exhaust that could otherwise damage the NOx sensors.

If a fault is identified by the following monitoring of the NOx sensor then; A reversible fault is created. If the fault is determined in three consecutive driving cycles then an irreversible (hard) fault is stored and the emissions warning light is activated.

The following faults are identified:

- Identification signal or correction factor is wrong
- Interrupted or short circuit between measuring probe and control unit of the NOx sensor
- Measured value outside of the defined area for a certain time
- Operating temperature is not reached after a defined heating period
- In coasting (overrun) mode (no nitrogen oxide expected) too great a distance from the measured value to zero is identified

- In the transfer from the load in coasting (overrun) mode the signal of the NOx sensor does not fall from 80% to 50% quickly enough (only NOx sensor before the SCR catalytic converter)
- If, despite a spike in the signal of the NOx sensor before the SCR catalytic converter there is not at least one defined change in the signal of the NOx sensor after the SCR catalytic converter, then this counts as implausible.

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