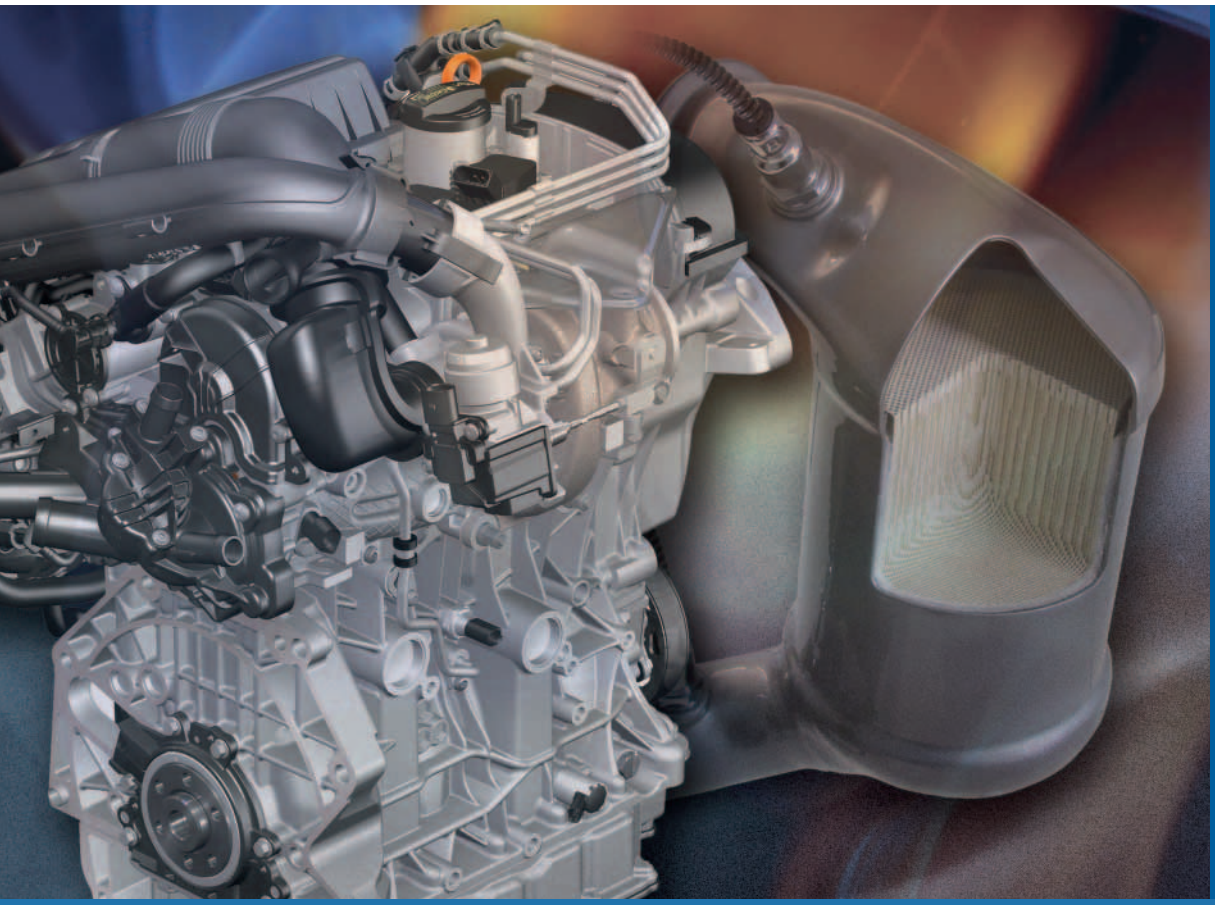
Service Training

Volkswagen

Self-study Programme 558

Close-coupled Petrol Particulate Filter

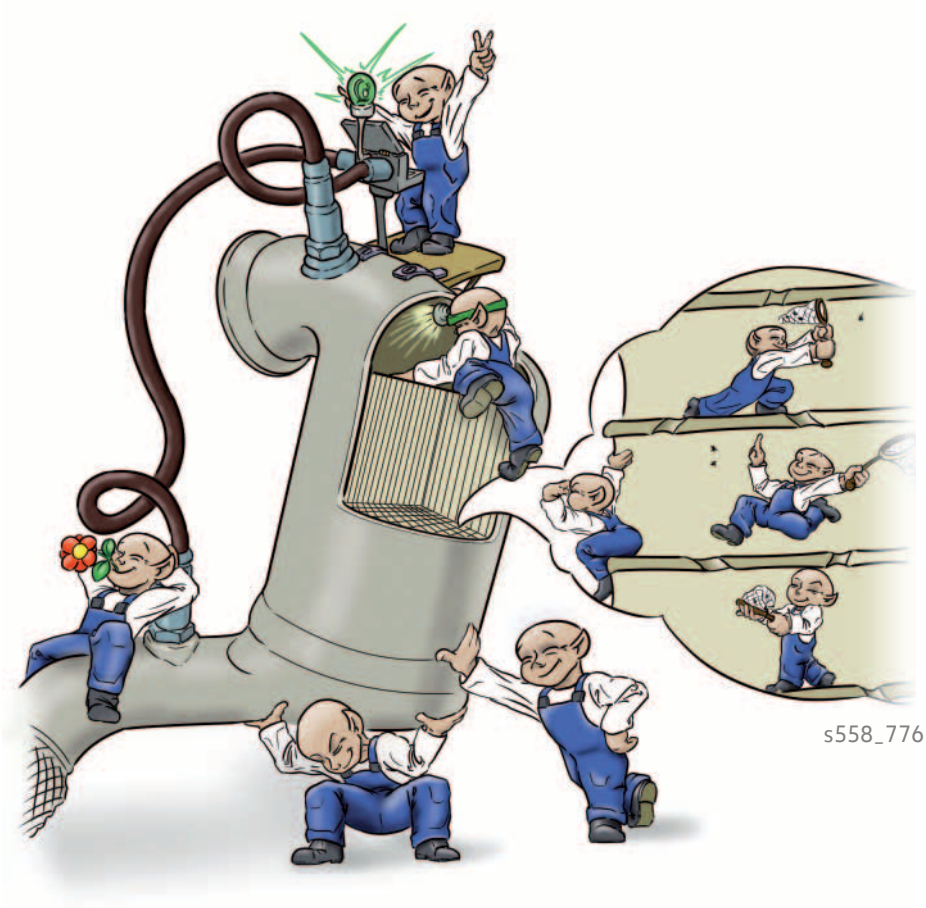
Design and function



Particulate filters have been standard in vehicles with diesel engines for a while now. This applies to passenger vehicles, goods vehicles, buses and even tractors.
The first diesel engines equipped with particulate filters were used as early as the 1970s in mining and in factories. The first car with a particulate filter was produced in 1985 exclusively for the American market.

Volkswagen produced its first diesel vehicle with particulate filter in 2004 for the European market.
On 1 September 2017, the emission limits for the particle number were lowered for type approvals of vehicles with direct injection petrol engines in the EU. A transition period of one year shall apply to new vehicles that already have a type approval.

Volkswagen is, however, already pointing the way and is fitting a 1.4-l 110-kW TSI petrol engine with particulate filter in the Tiguan. The model with this engine is spearheading new developments in the area of petrol engines.



The self-study programme shows the design and function of new developments.
The contents will not be updated.

For current testing, adjustment and repair instructions, refer to the relevant service literature.

Important Note

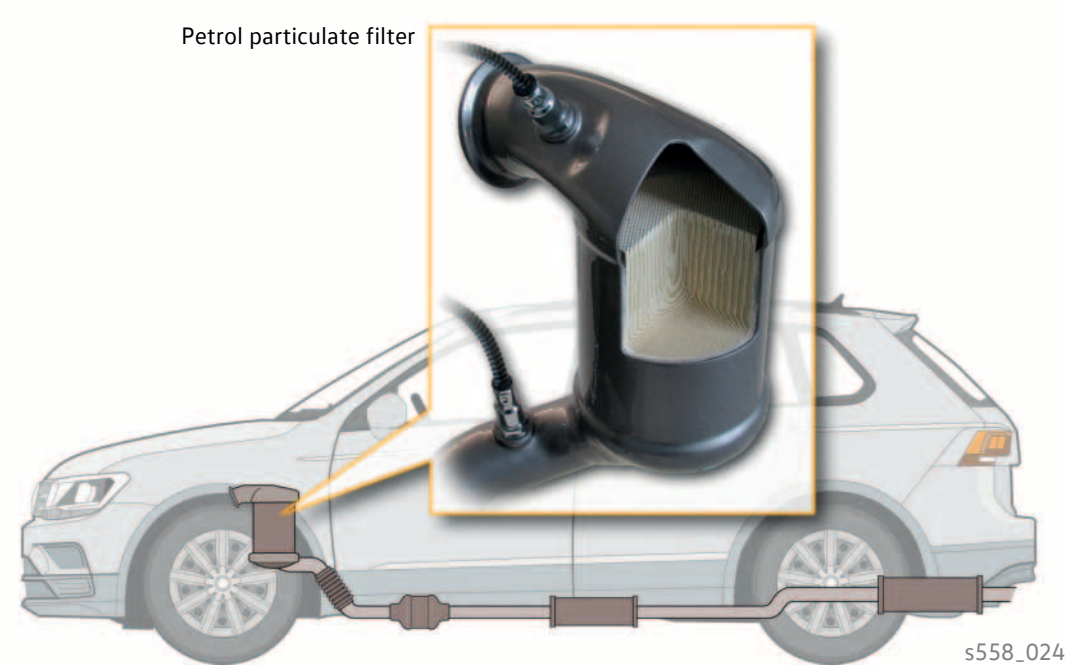
Contents

Particulate filters for petrol engines

A large amount of information is already available about particulate filters for diesel engines.
Diesel particulate filters (DPF) and petrol particulate filters work in a similar way.
So why has a Self-study Programme now been written on this subject?
Very simply:
this is a new technology for petrol engines and there are some interesting differences between diesel particulate filters and petrol particulate filters.

For a long time, petrol engines were considered completely unproblematic in terms of particulate emissions. It has been shown, however, that very fine particles can be produced when fuel is combusted in petrol engines. This has been caused in particular by the introduction of direct petrol injection. Additional emission standards for particulate matter have therefore applied to vehicles with direct injection, since the European standard 5a.

Petrol particulate filter



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You will find information on diesel particulate filters in, among others, Self-study Programmes
336 “The catalytic coated diesel particulate filter” and
403 “2.0l TDI Engine with Common Rail Fuel Injection System”.

Useful knowledge for practice

Particulate filters are used to protect the environment and our health.
The limits for particulate matter and particulate number are easily met when a particulate filter is employed.

Exhaust systems with petrol particulate filters are designed for the service life of the vehicles.
During "normal" driving, the driver therefore does not need to pay any attention to the particulate filter system nor to actively intervene.

This means that the particulate filter warning lamp will not light up during normal use of the vehicle.
If the particulate filter warning lamp still lights up, you will need to go on a regeneration drive (you will find detailed information on this from page 20).
During a regeneration drive, the engine may run with a slightly higher idle speed.
The engine may also sound rougher than usual.

Conclusion
Customers will drive models with Volkswagen petrol particulate filters in a more green-minded way.

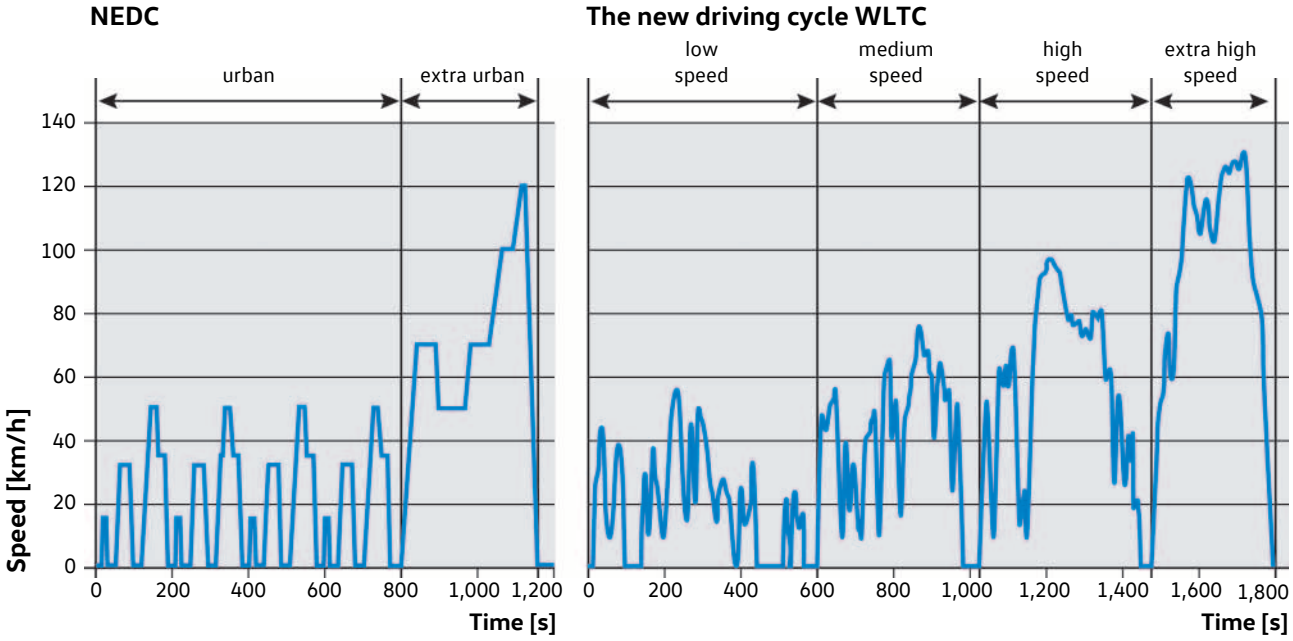
Generally only engine oils that comply with the corresponding Volkswagen standard may be used. If your engine is equipped with a particulate filter, these oils will help reduce the accumulation of ash in the particulate filter.
You will find further information about this on page 11.

Information on exhaust gas legislation

Exhaust gas legislation will become even stricter in the EU over the coming years.
New exhaust gas testing methods, lower pollutant limits and new measuring systems set new and higher requirements for engine development.

New exhaust gas testing method

On 1 September 2017, the previous "New European Driving Cycle" (NEDC) was replaced by the "Worldwide harmonized Light-duty vehicles Test Cycle" (WLTC) for type approvals.
The new test is more dynamic and thus closer to everyday driving.



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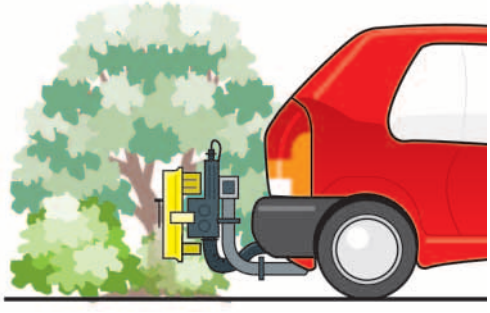
Among other things, the maximum speed of approximately 120 km/h will rise to approximately 131 km/h and the whole driving cycle will take longer.

Real driving emissions (RDE)

In addition to the WLTC on the test bed, another test cycle is driven on the road.
A transportable emissions measuring system is fitted to the vehicle for this purpose.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Emission codes and emission standards

Vehicles are registered in accordance with emission codes, for example, EU6W.
The emission code includes among other things the exhaust gas testing method and one of the emission standards. The limits for exhaust emissions are defined in the emissions standard.

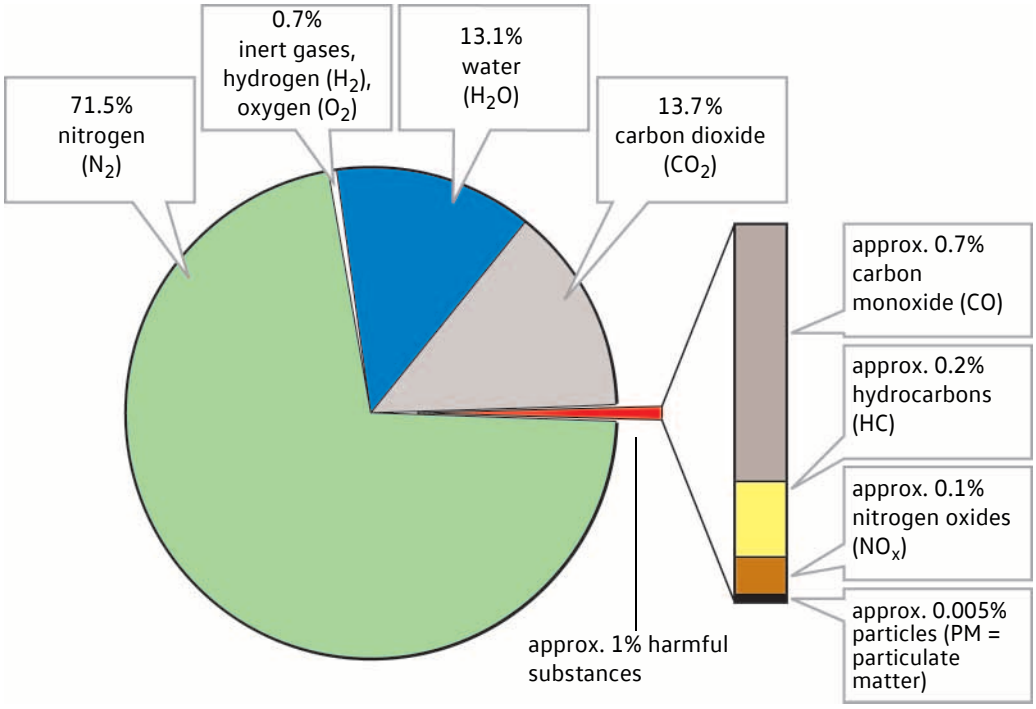
The emission standard Euro 5a introduced particulate matter (PM) limits for petrol engines with direct injection. The following table shows how the limits for particulate matter (PM) and particulate number (PN) have changed:

Emission standard	For type tests from	Change
Euro 5a	1 September 2009	- 0.05 g/km limit for particulate matter (PM) introduced
Euro 6b	1 September 2014	- Limit for particulate matter (PM) lowered to 0.045 g/km - $6x10^{12}$ per kilometre limit for particulate number (PN) introduced
Euro 6c and 6d	1 September 2017	- Limit for particulate number (PN) reduced to $6x10^{11}$ per kilometre

Note: the Euro 6a emission standard does not apply to petrol engines.

You will find detailed information on exhaust gas legislation in Self-study Programme 573 "Vehicle Emissions Laws 2017".

The composition of exhaust gases from petrol engines



Only approx. 1% of the exhaust gases are classified as harmful substances. These are:
- approx. 0.7% carbon monoxide (CO)
- approx. 0.2% hydrocarbons (HC)
- approx. 0.1% nitrogen oxides (NO_x)
- approx. 0.005% solids (particulate)

We presume that lambda 1 will be complied with in the figures for the composition of exhaust gases.
This specification is based on an optimum ratio of fuel mass and air mass.
Approx. 14.7 kg of air is required to fully burn 1 kg of petrol assuming there is an oxygen content of 21%. This optimum ratio of air and fuel mass is also known as the stoichiometric ratio. The following rules apply here:
- If the actual air mass present is equal to the air requirement, the ratio is the same (lambda=1).
- If the actual air mass present is greater, the ratio is also greater and the lambda value is therefore greater than 1.
- If the air mass present is smaller, the lambda value is less than 1.

A lambda value greater than 1 therefore indicates a lean fuel/air mixture and a lambda value less than 1 indicates a rich fuel/air mixture. The following applies to the composition of the exhaust gas:
- If the mixture is slightly lean, the proportion of nitrogen oxides (NOx) in the exhaust gases will rise.
- If the mixture is rich, the proportion of hydrocarbons (HC) and carbon monoxide (CO) will be higher.

The formation of particles

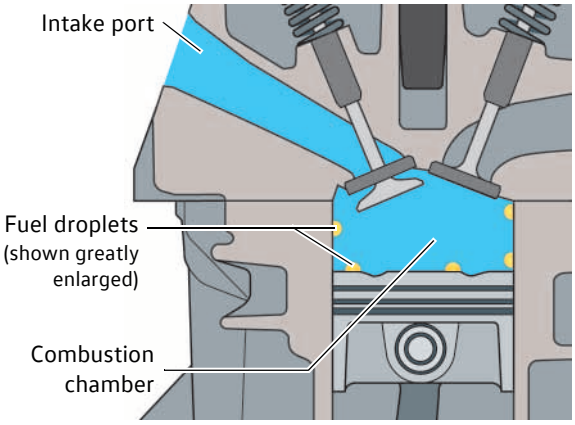
We need to deal with the following questions before making a statement on the formation of particulate matter in petrol engines:

Is the myth true that particles are formed only in petrol engines with direct injection during the combustion process, but not in engines with manifold injection?
It is actually true that petrol engines with direct injection have slightly higher particle emissions than petrol engines with manifold injection. This only applies to cold starts and the first 1–2 minutes following that, however.

How are soot particles formed in petrol engines?

At low temperatures, it is difficult to fully atomise the fuel droplets before combustion in petrol engines with direct injection. The reason for this is the short, direct path from the injector to the combustion chamber.

The path is longer in engines with manifold injection. The small droplets evaporate almost completely due to the longer path and the swirling that occurs.



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You will find measures taken inside the engine to reduce soot particles in direct injection engines on page 12.

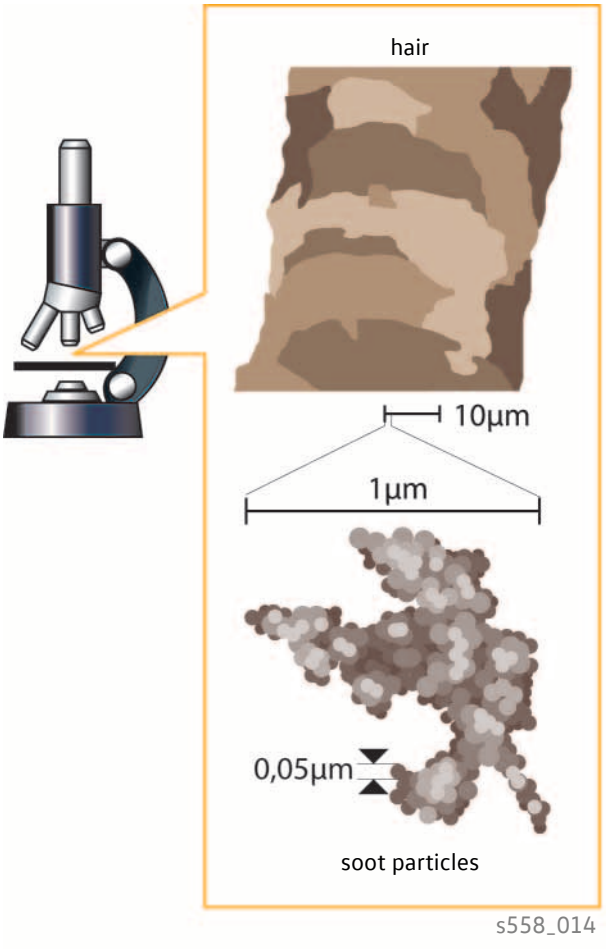
The advantages of direct injection do outweigh the disadvantages by far, however. These are:
- Lower fuel consumption
- Greater power efficiency
- Overall lower emissions

Soot and ash particles

Two terms need to be differentiated when we talk about particles in exhaust gas. There are two different substances or mixtures of substances that have different causes: soot particles and ash particles.

Soot particles

Soot particles mainly consist of carbon. They can, however, be contaminated with other molecules like unburnt hydrocarbons, sulphur compounds, metal oxides and water.
Soot is formed when there is not enough oxygen to completely burn the carbonaceous fuel or if the fuel is not sufficiently atomised. The particles formed measure slightly more than 0.05 micrometres (µm) in petrol engines similar to those in diesel engines. One micrometre is one thousandth of a millimetre.
After leaving the combustion chamber, solid particles are safely deposited in the particulate filter. Volatile adhering substances evaporate very quickly and do not accumulate in the particulate filter.

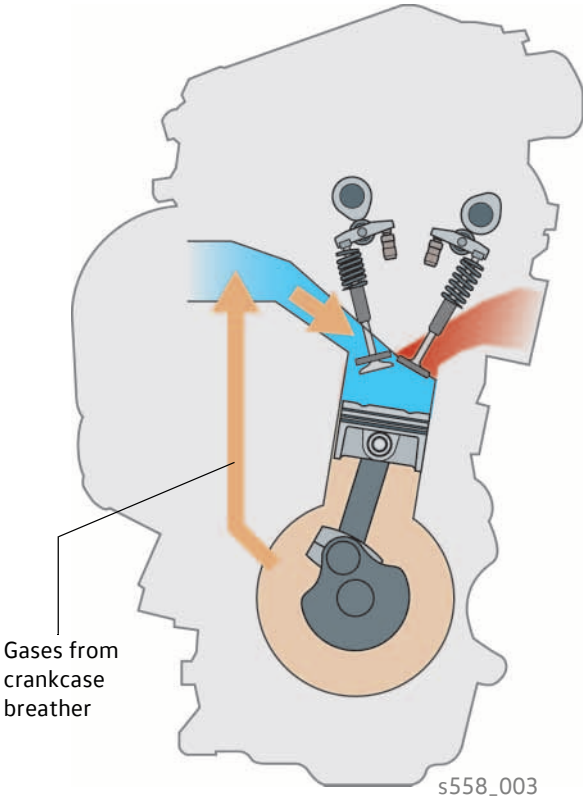


The structure of soot particles can only be seen when they are magnified to a very high degree.

Ash particles

Ash particles are slightly bigger than soot particles. In petrol engines, they can only be caused by additives in the engine oil.
The oil can, for example, reach the combustion chamber via the crankcase breather and thus cause the formation of ash particles. Therefore, it is extremely important for service departments to observe the correct oil standard for the respective engine.

Unlike soot particles, ash particles are not burnt during the particulate filter regeneration.



The latest engine oils in accordance with Volkswagen standards are low-ash oils.
They contain hardly any additives like sulphur, zinc, calcium or phosphor. Ash particles are formed when these elements are burnt.

The measures inside the engine

The EA211 engine family includes the product line featuring the 1.2-l and 1.4-l TSI engines with toothed belt. This engine family was conceived for the modular transverse matrix (MQB). During development, the engineers attached great importance to reducing the particles in the exhaust gas.
Measures were taken inside the engine.

These measures are, for example:

- Increasing the fuel pressure
  The direct injection engines from the previous EA111 engine family worked with a fuel pressure of approx. 40 bar to 50 bar at idle and a maximum pressure of approx. 130 bar.
  The EA211 engines, depending on the variant, already reach a pressure of approx. 140 bar at idle and a maximum pressure of up to approx. 350 bar. The fuel droplets become smaller and they atomise faster as a result.
- Modified combustion chamber as well as modified injectors and injection times
  These measures reduce the formation of particles.

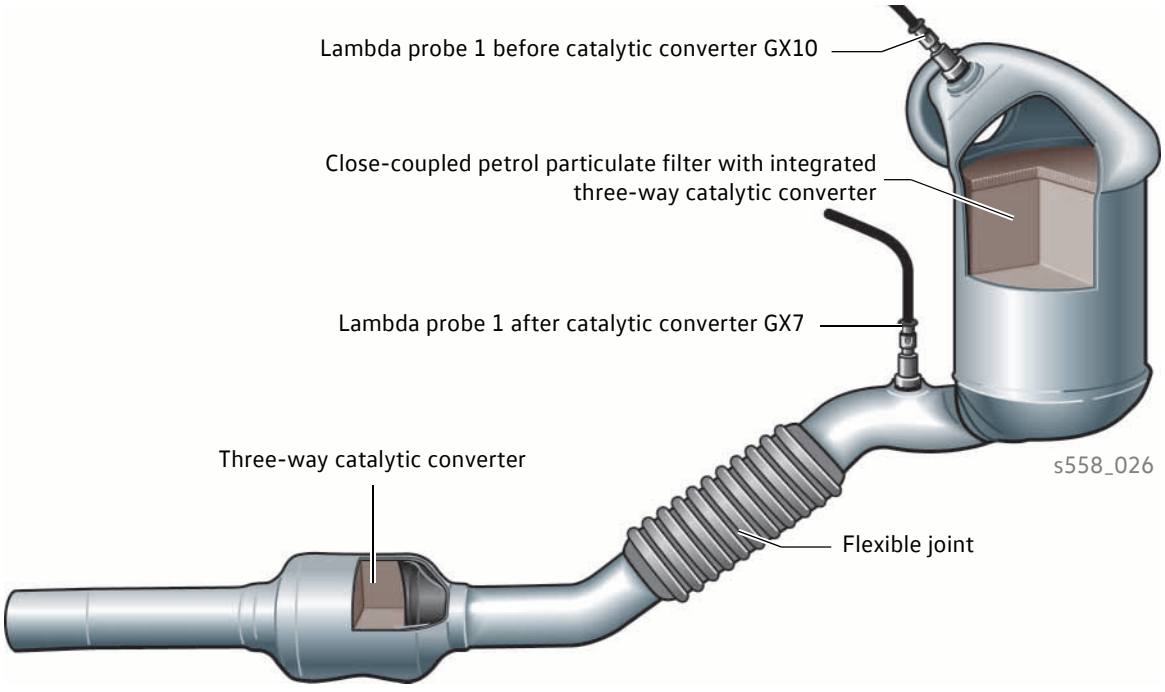
The aforementioned measures are very effective so that the enhanced engines in the EA211 engine family fulfill all current emission standards. Nevertheless Volkswagen has decided to already introduce a petrol particulate filter.

You will find further information on the EA211 engine family in Self-study Programme no. 511 “The New EA211 Petrol Engine Family”.

The measure outside the engine

The measure outside the engine for reducing particles is a particulate filter.
This year, Volkswagen is supplying the first vehicles with a catalyst-coated, close-coupled petrol particulate filter for the European market. The Tiguan featuring the 1.4-l 110-kW TSI engine with front-wheel drive and manual gearbox is the first model to use this technology.

The petrol particulate filter is bolted directly onto the turbocharger in this system. A three-way catalytic converter is integrated into the petrol particulate filter in the form of a coating. Another three-way catalytic converter is fitted in the exhaust pipe after the subsequent flexible joint.

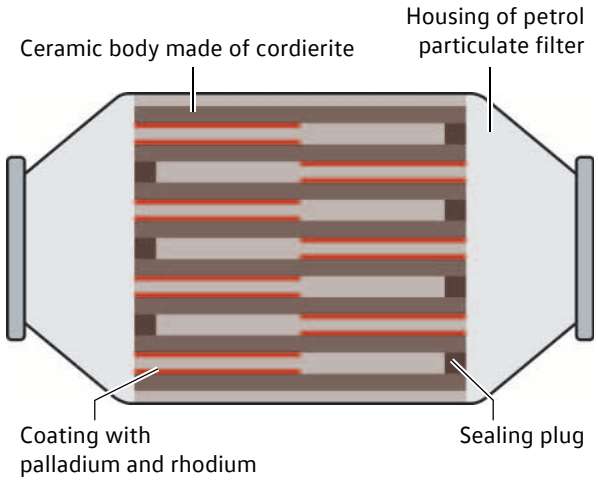


The close-coupled petrol particulate filter is also known as a four-way catalytic converter because it has an integrated catalytic coating.

Petrol particulate filter

Design

The petrol particulate filter has coated channels like the three-way catalytic converter.
The carrier material is a ceramic module made from cordierite. The channel ends in the ceramic body are sealed alternately by plugs.
The material used for the ceramic body is porous and functions as a filter at the same time.



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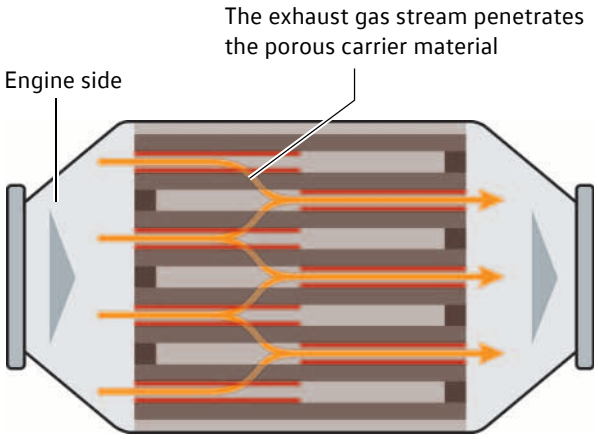
How it works

Due to this design, the exhaust gas needs to penetrate the channel walls with the particles in order to pass from the engine side of the ceramic module to the side away from the engine. Even though the particles are smaller than the pores in the ceramic body, they are still reliably filtered out.
This is down to the Brownian molecular motion of small particles.



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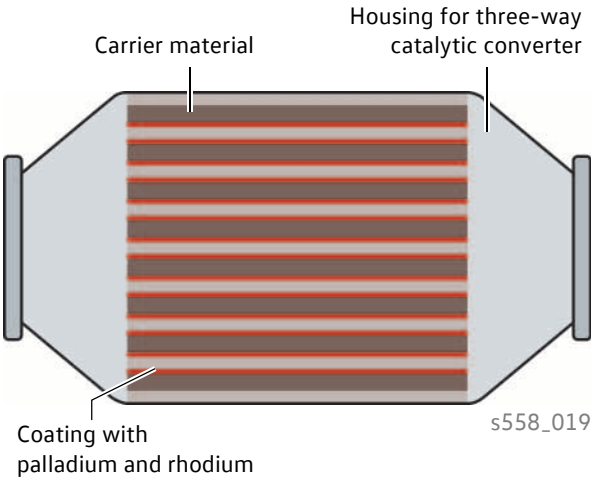
Brownian molecular motion

In 1827, Scottish botanist Robert Brown observed that tiny particles in liquids move suddenly and randomly. Later it was discovered that these movements follow a general principle, which also applies to gases. The movement is caused by heat-related collisions of small particles.
The warmer the medium, in which the particles are moving, the faster and more vigorous the Brownian molecular motion.
The continuing collisions between the particles cause them to be propelled against the walls of the pores and to stick there. The filter effect of the ceramic body is based on this process.

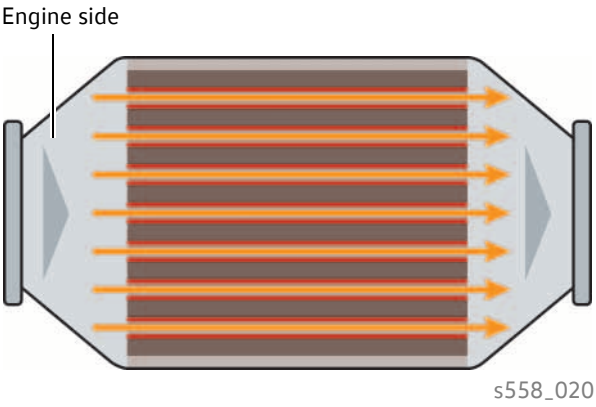
Comparison with three-way catalytic converter

By definition, a catalyst is a substance that participates in a chemical reaction without changing itself. The body of the three-way catalytic converter can consist of different materials, for example, metal or ceramic. The channels in the three-way catalytic converter are coated with a catalytic material and not closed.

This coating contains elements like palladium and rhodium. Older catalytic converters also use platinum. These catalytic metals cause pollutants to be oxidised or reduced to non-toxic compounds like nitrogen (N_2), carbon dioxide (CO_2) and water (H_2O).



In contrast to the petrol particulate filter, the exhaust gases flow through the channels of the catalytic converter body without penetrating its walls.



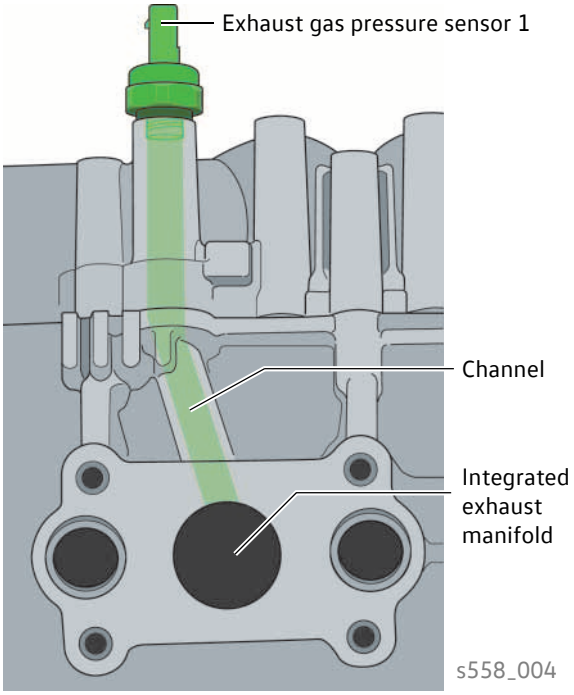
Sensors

Exhaust gas pressure sensor 1 G450

Fitting location and task

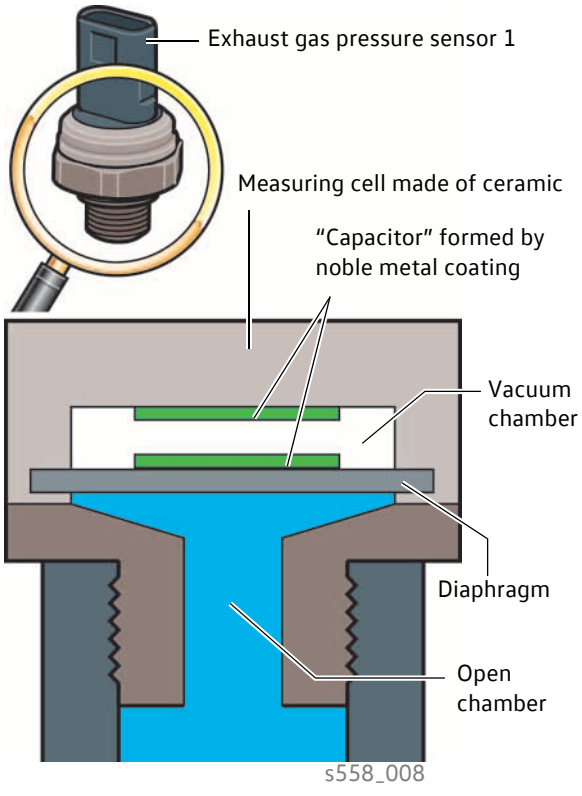
The exhaust gas pressure sensor 1 is screwed into the camshaft housing from above.
It has the task of measuring the exhaust gas pressure before the turbocharger and thus also before the particulate filter.
It is connected to the integrated exhaust manifold via a channel in the camshaft housing and in the cylinder head.

After removal, the pressure sensor may not be reused and must be renewed because it has an integrated seal.



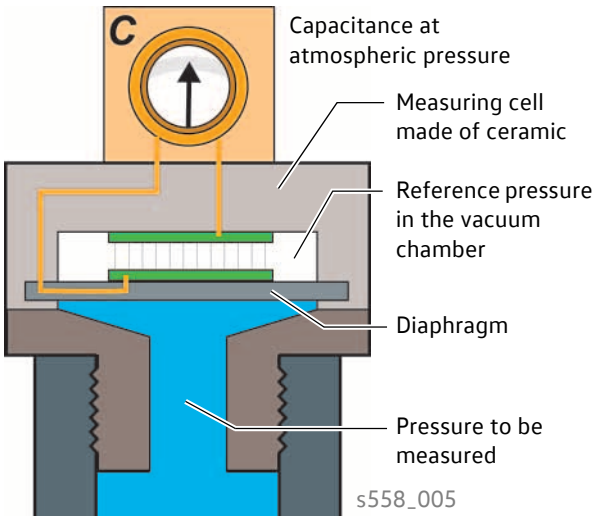
Design

This three-pole pressure sensor with evaluation electronics basically consists of a ceramic measuring cell. The measuring cell is divided into two chambers by a thin diaphragm coated with a noble metal. One of the chambers is sealed off from the external air pressure and contains a vacuum. This chamber is henceforth called the vacuum chamber.
The other chamber is connected to the outside air pressure, which, in this case, is the exhaust gas pressure before the turbocharger (called "open chamber" in the illustration).
The wall of the vacuum chamber opposite the diaphragm is also coated with a noble metal. In this way, the two opposing coatings in the vacuum chamber form a capacitor whose capacitance varies according to the distance between the two coatings.



How it works

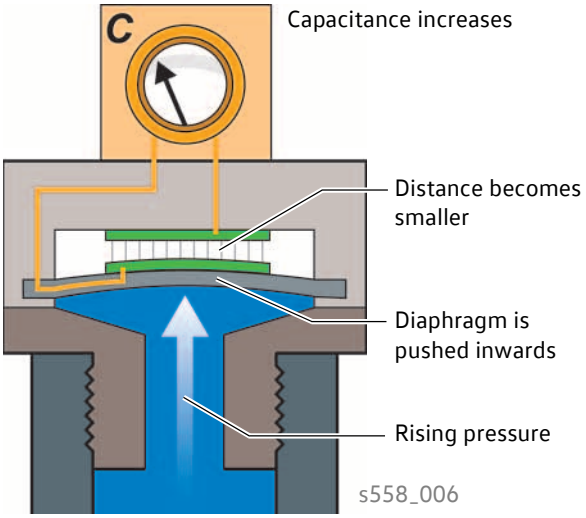
The pressure sensor measures the exhaust gas pressure and compares it with a vacuum as a reference pressure. This method rules out inaccuracies caused by fluctuations in the atmospheric air pressure that are caused by the weather or changing altitudes.
The vacuum reference pressure is, as described, "built into" the pressure sensor.



If the exhaust gas pressure changes, the diaphragm in the ceramic cell will be deformed.
If the exhaust gas pressure rises, the diaphragm will be pressed towards the opposite coating. The distance between the two coatings is reduced and the capacitance increases.

If the exhaust gas pressure decreases, the diaphragm will be deformed in the other direction. The distance between the coatings is enlarged and the capacitance is reduced. In this way, the pressure in the exhaust manifold can be determined precisely and transmitted as an analogue voltage signal.

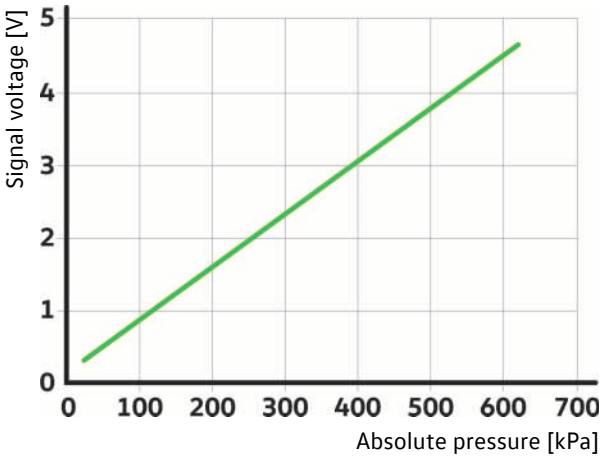
The described changes to the capacitance are very small. Therefore the sensitivity of the sensor electronics have been set very high.



Engine management system

Signal use

The engine management system determines the pressure before the particulate filter by using the analogue voltage signal from the sender. A linearly rising voltage corresponds with a linearly rising pressure.
A pressure of approx. 100 kPa (100 kilopascal = 1 bar) corresponds with a signal voltage of approximately 0.8 V.
The pressure unit pascal is the international measuring unit for pressure.
100 kPa are 100,000 Pa.



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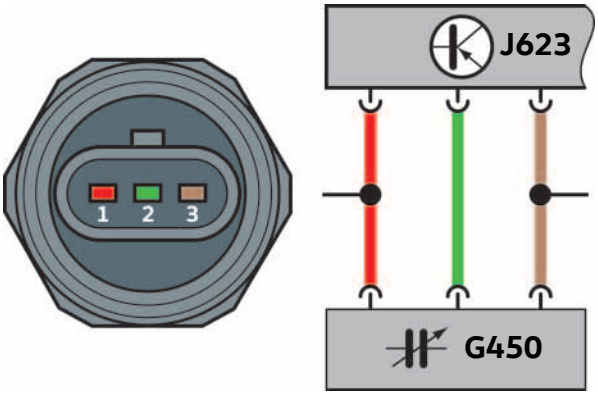
The signal is used to detect blockages. If the pressure exceeds a threshold value model programmed into the engine/motor control unit, the control unit presumes there is a blockage in the exhaust system. The signal is also used for pilot control of the charge pressure regulation.

Electrical connection

The sender G450 is connected via a three-pole wire to the engine/motor control unit J623.



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Positive supply: +5 volts
Signal voltage
Earth

Effects upon failure

A detected fault is stored as an entry in the event memory.

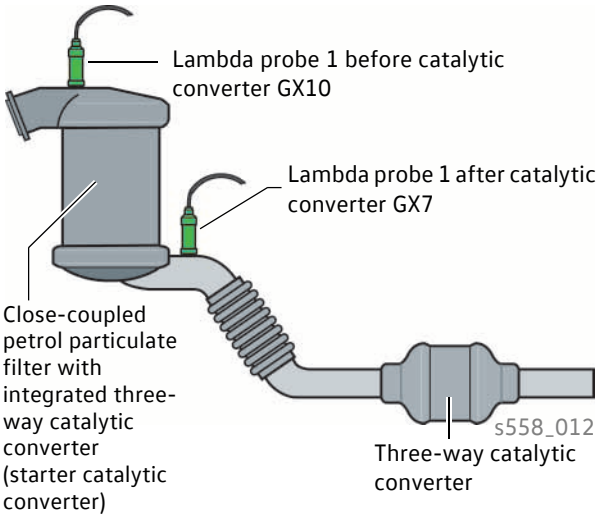
An accumulation or calculation model programmed into the engine/motor control unit J623 is used to detect the level of soot and ash.

An entry in the event memory made by the blockage detection system can also be caused by a blocked silencer or catalytic converter.

Lambda probes

Two step-type lambda probes are used for the exhaust system with petrol particulate filter.
The lambda probe before the catalytic converter is connected to a "constant controller" in the engine/ motor control unit.

You will find more detailed information on step-type lambda probes with continuous controller in Self-study Programme 539 "1.0-l 3-cylinder TSI Engine".



Fitting location and task

The lambda probe before the catalytic converter is fitted upstream of both catalytic converters. The lambda probe after the catalytic converter is between the two catalytic converters. The three-way catalytic converter integrated into the petrol particulate filter acts as the main converter. This is also one reason for the fitting location of the lambda probe 1 after catalytic converter GX7. The catalytic converter that performs the main conversion work is monitored.

Signal use

The signal from the lambda probes is used for the following functions:
Lambda probe 1 before catalytic converter GX10:

- Regulation of the fuel/air mixture

Lambda probe 1 after catalytic converter GX7:

- Functional check of the starter catalytic converter and adaptation of the lambda probe 1 before catalytic converter
- Indirect monitoring for damage to the petrol particulate filter

How indirect monitoring for damage to the petrol particulate filter works

The carrier and filter material in the particulate filter is more heat resistant than the catalytic converter coating. Therefore an excessively high temperature will cause the catalytic layer to stop functioning before the particulate filter is damaged. The engine/motor control unit can therefore indirectly determine that the petrol particulate filter is damaged by using the signal from the probe after the catalytic converter and by detecting a starter catalytic converter malfunction. The exhaust emissions warning lamp K83 flashes if there is a catalytic converter fault and an entry is made in the event memory.

Effects upon failure

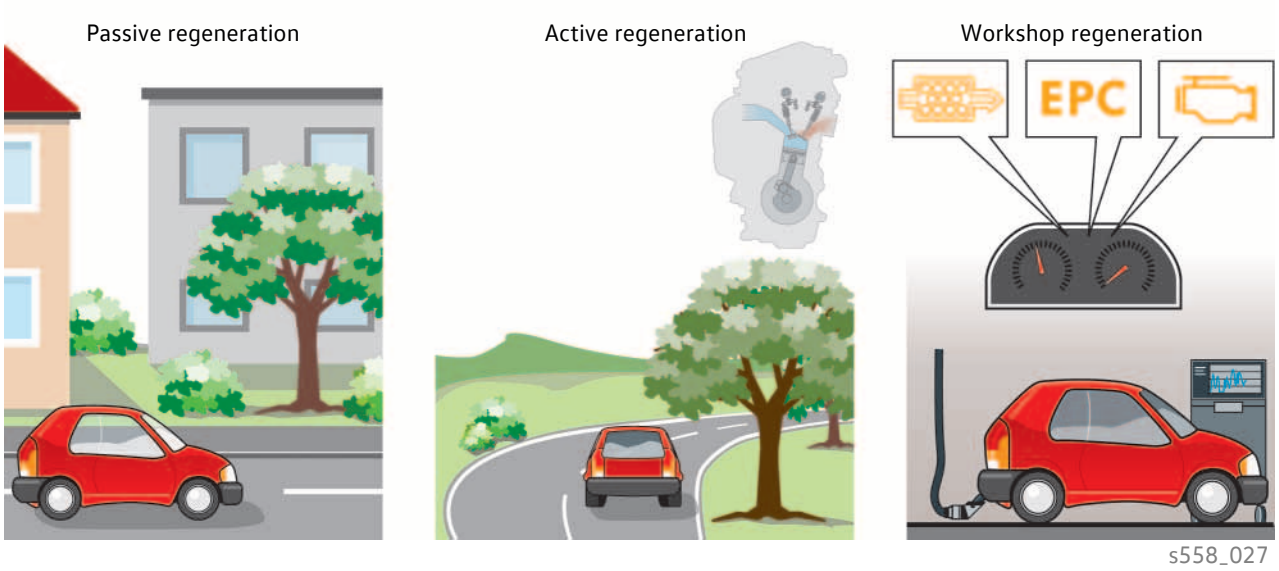
If the lambda probe 1 before catalytic converter GX10 fails, the system will switch from lambda regulation to lambda control and the exhaust emissions warning lamp K83 (MIL) will light up. If the lambda probe 1 after catalytic converter GX7 fails, the lambda regulation will still function. The exhaust emissions warning lamp K83 (MIL) will light up. An entry will be made in the event memory in both cases.

Particulate filter regeneration

Since particles are produced in direct petrol injection engines only during and shortly after cold starts, regeneration is rarely necessary. The frequency and duration of the regeneration processes vary according to the accumulation level and the conditions for regeneration.
Three types of regeneration are distinguished:

- Passive regeneration
- Active regeneration
- Workshop regeneration

An accumulation or calculation model programmed into the engine/motor control unit is used to detect soot and ash accumulation. The engine/motor control unit determines the accumulation changes in the particulate filter from the intake air temperature, coolant temperature, engine speed and engine load.



Passive regeneration
Passive regeneration takes place almost constantly when the vehicle is moving without the engine/motor control unit using special measures.
The requirement is that the journey is long enough to allow the petrol particulate filter to reach the required temperature of approx. 600°C. Oxygen is required to regenerate the particulate filter. It is mainly supplied by the overrun fuel cut-off. The soot particles are then combusted into carbon dioxide (CO_2) if the operating temperature is sufficiently high with the aid of this "additional" oxygen.

Active regeneration

If the accumulation in the particulate filter exceeds a certain value despite passive regeneration, measures will be initiated that will support the regeneration.
If the driver's driving behaviour is not sufficient for regeneration, they will be informed by the particulate filter warning lamp K331 that a regeneration drive is necessary (see table on next page).

Workshop regeneration

If the accumulation in the particulate filter exceeds a set limit because, for example, the driver ignores the regeneration drive request, active regeneration while the vehicle is moving may not be sufficient in some circumstances.
The engine management system additionally switches on the exhaust emissions warning lamp K83 (MIL) and the electronic power control fault lamp K132 (EPC lamp). A message will also appear on the display asking the driver to visit a workshop.

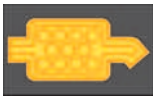
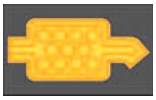
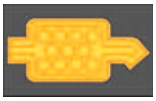
The warning lamps light up yellow in the context of the particulate filter and do not flash.
The particulate filter system can therefore never be a reason for telling the customer to stop immediately.

The workshop regeneration is performed with the aid of the Guided Fault Finding.
The exhaust extraction system in the workshop needs to be configured for temperatures of at least 300° Celsius.
Only the funnels VAS 5199 or VAS 5199/12 may be used as exhaust extraction funnels.

Please observe the current information in the workshop information.

Accumulation levels

You will see different accumulation levels with the respective measures in the following table. During normal driving, the particulate filter warning lamp K331 should not light up. The reason is that the passive regeneration for the petrol engine takes place constantly at temperatures above 600°C in the particulate filter. Additional active measures are therefore normally not necessary.
For safety reasons, active regeneration occurs cyclically every 2,000 km regardless of the accumulation level.

Accumulation*	**Measures**
Up to approx. 15%	- No measures active - Passive regeneration during “normal” engine running
From approx. 15%	Active regeneration by measures that support the regeneration.
From approx. 55%	Active regeneration by measures that support the regeneration. In addition to this: - Particulate filter warning lamp K331 lights up - Entry in event memory: “Particulate Filter Bank 1, Warning Lamp Active” - Regeneration drive by the driver required 
From approx. 70%	- Particulate filter warning lamp K331 lights up - Electronic power control fault lamp K132 lights up Meaning: reduction in power - Exhaust emissions warning lamp K83 (MIL) lights up - Entry in event memory: “Particulate Filter Restriction Soot Accumulation Bank 1” - Workshop regeneration necessary   
Accumulation limit reached (100%)	- Particulate filter warning lamp K331 lights up - Electronic power control fault lamp K132 lights up Meaning: reduction in power - Exhaust emissions warning lamp K83 (MIL) lights up - Entry in event memory: “Particulate Filter Restriction Soot Accumulation Too High Bank 1” - Workshop regeneration no longer possible, petrol particulate filter needs to be renewed   

* The specified percentages for accumulation levels are only approximate reference points.

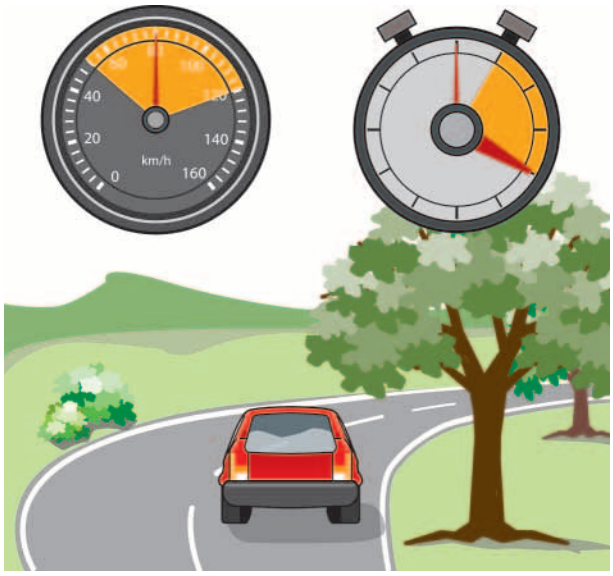
To aid verifiability, the entry “Particulate Filter Bank 1, Warning Lamp Active” will remain in the event memory for several more driving cycles after the particulate filter warning lamp K331 goes out.

The following measures can also be taken during active regeneration:

- The Active Cylinder Management (ACT) and the stop/start function can be switched off according to the temperature.
- The idling speed may increase to approx. 1,000 rpm. It may even rise to 1,450 rpm if the particulate filter warning lamp K331 is lit up to guarantee better regeneration when the vehicle is stationary.

Regeneration drive

The Owner's Manual recommends that customers go on a regeneration drive if the particulate filter warning lamp K331 lights up. Driving at speeds between 50 and 120 km/h supports the regeneration process. Applicable speed limits and recommended gears should be observed during the drive.
The particulate filter warning lamp K331 will go out automatically once the filter has been regenerated.
A regeneration drive generally takes approx.
5 to 20 minutes.



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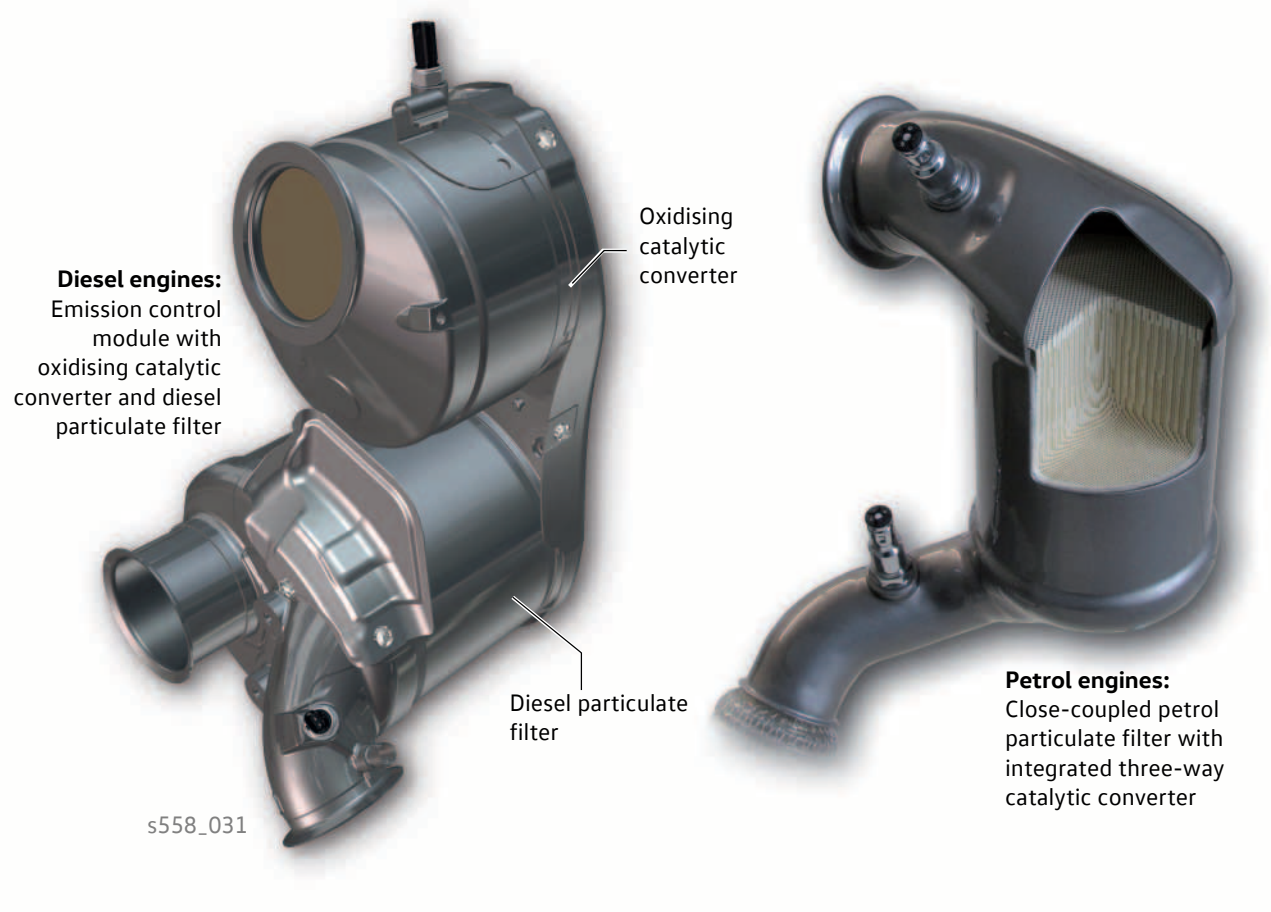
Other ways of driving also lead to regeneration as long as the engine is running.

A comparison of particulate filters for petrol and diesel engines



What is the same?

- Both types of engine produce soot and ash particles during combustion.
- The particles are roughly the same size with both engine types.
- The particulate filters are regenerated passively and actively in both systems. However, only the soot particles are oxidised during the process, not the ash particles.
- Low-ash oils must be used as engine oil in both systems.
- A filter accumulation limit is programmed into the engine/motor control unit for the petrol particulate filter similar to the diesel particulate filter. Once a certain percentage of the accumulation limit has been reached, the particulate filter warning lamp K331 will light up to inform the driver that a regeneration drive is necessary.
- The text about regeneration drives in the Owner's Manual has been standardised for both systems.
- If you do not go on a regeneration drive and the accumulation increases, a workshop regeneration process will be necessary for both systems.

What is different?

- Diesel engines produce more soot than petrol engines.
- Direct injection petrol engines produce particles mainly during cold starts at low ambient temperatures and immediately after the engine is started.
  Diesel engines produce particles during almost the whole time they are running.
- It is more difficult to reach the temperature required for particulate filter regeneration with the diesel system than with a petrol engine.
- Due to the combustion process with excess air, there is always sufficient oxygen for regeneration with diesel engines, but not with petrol engines.
- In many particulate filter systems for diesel engines, the first active regeneration is carried out after you drive a distance of 100 km. This does not apply to petrol engines with particulate filters, however.
- Depending on the engine variant, the ash accumulation in the particulate filter should be read during inspections of diesel engines with particulate filters (for the first time at 180,000 km, for example), but not for petrol engines with particulate filters.

Test your knowledge

Which answers are correct?

One or several of the given answers may be correct.

1. How is the close-coupled petrol particulate filter in the Tiguan configured for the 1.4-l TSI engine?

❒ a) Like a conventional three-way catalytic converter, it consists of coated channels, whose channel ends are always sealed alternately.

❒ b) The petrol particulate filter is a separate component that is upstream of the close-coupled three-way catalytic converter.
The catalytic converter can therefore not be damaged by particles.

❒ c) A catalytic coating is integrated into the particulate filter.

2. What type of signal does the exhaust gas pressure sensor 1 G450 send to the engine/motor control unit J623?

❒ a) A SENT signal (SENT = Single Edge Nibble Transmission)

❒ b) A LIN bus signal

❒ c) An analogue voltage signal

3. What measures have been taken inside the EA211 engine to prevent particles being formed?

❒ a) The fuel pressure has been reduced so that the fuel droplets are not sprayed onto the piston crown.

❒ b) The fuel pressure has been increased.

❒ c) The combustion chamber and the injectors have been modified.

4. What is recommended to customers if only the particulate filter warning lamp K331 lights up while driving?

❒ a) They need to go to a workshop.

❒ b) They should switch off the engine immediately.

❒ c) They should go on a regeneration drive.

5. In which case should the particulate filter warning lamp K331 flash?

❒ a) It should never flash.

❒ b) From a soot accumulation of approx. 60% in the particulate filter.

❒ c) From a soot accumulation of approx. 80% in the particulate filter.

❒ d) When the customer drives at the right speed during the regeneration drive.

Answers:
1. a), c); 2. c); 3. b), c); 4. c); 5. a)

000.2813.13.20 Technical status 09/2017

Volkswagen AG
After Sales Qualification
Service Training VSQ-2
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