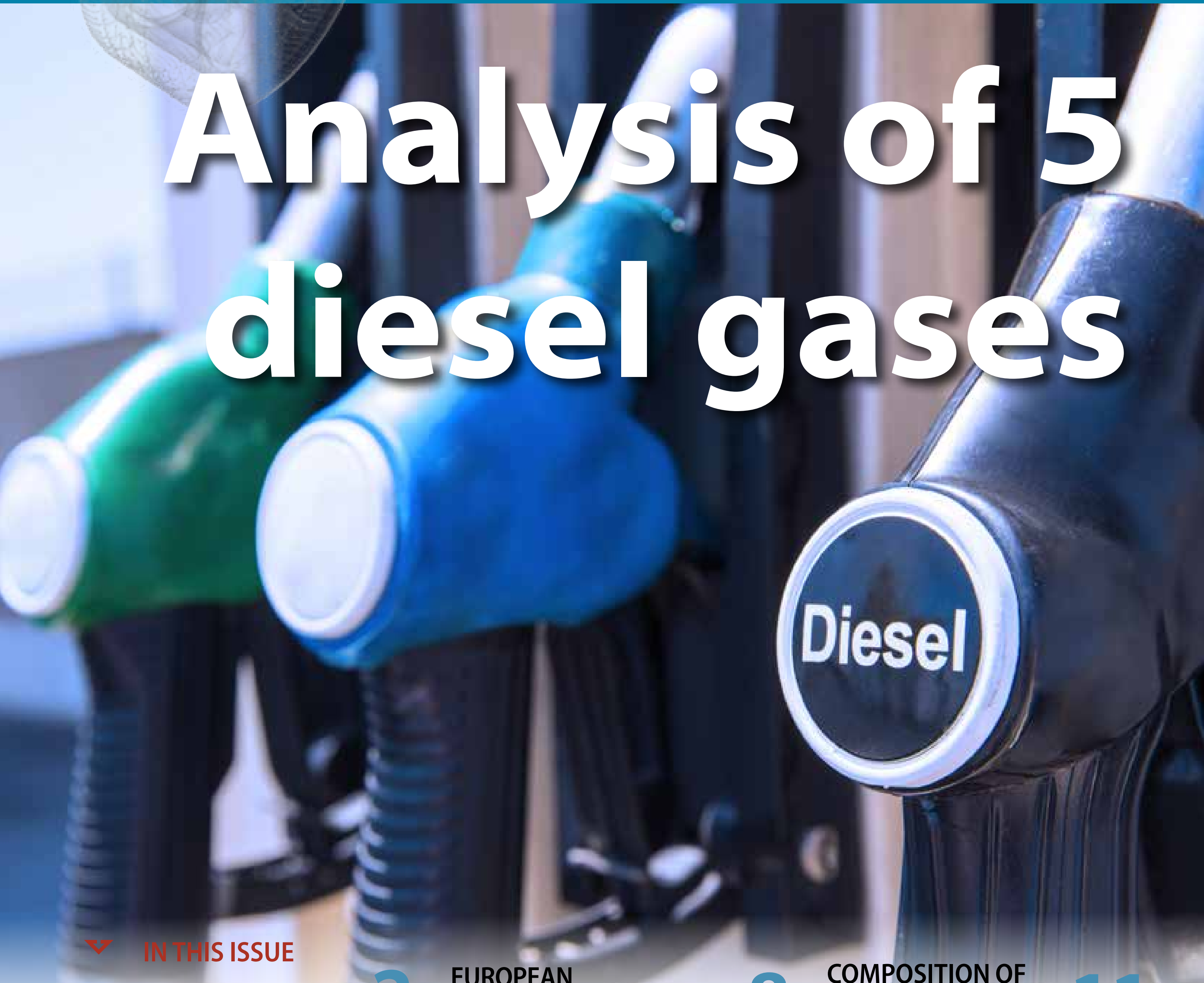
18

Eure!TechFLASH

THE UP-TO-DATE TECHNICAL INSIGHT IN AUTOMOTIVE TECHNOLOGY & INNOVATIONS

EDITION 18

Analysis of 5 diesel gases



IN THIS ISSUE

EureTechFlash is an AD International publication (www.ad-europe.com)

Download all EureTechFlash editions at www.eurecar.org

INTRODUCTION

Since the creation of internal combustion engines, the energy output of the diesel engine has been much higher than its direct competitors, a factor, which, combined with the cost of the fuel, has led to its absolute dominance in industrial, heavy transport and collective mobility applications.

Its application in light motor vehicles was initially limited due to the fact that diesel engines were more expensive, heavier, louder and had more limited operating flexibility. For many years, the complexity and precision of their fuel feed systems increased production costs, which were ultimately offset as a result of the evolution of machining techniques and the automation of the machinery.

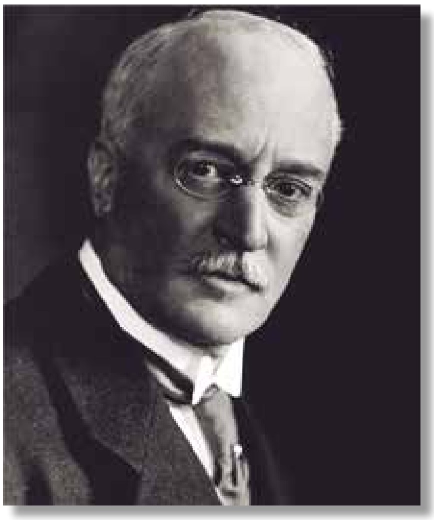
Shortly thereafter, the development of digital electronics and their application to engine fuel injection systems revolutionized the automotive world by generating a spectacular improvement in the performance of diesel engines.

The response by end consumers to the combination of improved operating economy and equal or better performance was not long in coming, with diesel vehicles topping the sales figures for several years running.

The rapid transformation of the automotive fleet in some counties and the mass adoption of diesel vehicles in large cities in just a few short years became a reality with dangerous consequences. The particulate emissions of diesel engines, in recent years have made it the source of a public health problem that the authorities are attempting to solve by means of increasingly-stringent type approval requirements and periodic inspections.

Mandatory compliance with anti-pollution standards has sparked the technical evolution of diesel engines and the development of new pollutant-reduction systems whose performance and proper functioning can only be verified by the final chemical composition of the exhaust gases. The measurement of the proportions and variation of certain substances generated by combustion also makes it possible to diagnose certain specific anomalies that the self-diagnosis programs of the vehicles are unable to identify.

BRIEF CHRONOLOGY OF THE DIESEL ENGINE



In 1892, the German Rudolf Diesel invented and patented and amazed the world with a self-ignition engine that ran on heavy fuels, which were later dubbed diesel engines. After the death of its creator, the diesel engine increased its fame and improved its reputation. Due to its high output, in just a few years it became the focus of industry and heavy transport, after the initial expansion in military applications.

In 1904 the first submarine equipped with a diesel engine was built. It combined an electric motor for propulsion while submerged and a diesel engine to recharge its batteries and for propulsion when on the surface.

Production of lorries with diesel engines began in 1920, but it wasn't until 1930 that diesel locomotives began to proliferate, thanks in part to the adoption of the turbocharger, which increased output by almost 30%. In 1939 25% of the world's maritime transport used diesel propulsion.

In 1922, Robert Bosch began to develop the injection system for diesel engines and developed a wide variety of fuel injection pumps. In 1927, the first mass-produced batch of injection pumps was produced, making it possible to conquer the farm machinery and industrial vehicle sectors in a short time.

Comparatively, a diesel fuel injection system required between 6 and 10 times more parts than a conventional carburettor, at a much higher cost. Later, the automation of machinery produced a great step forward in this aspect with a significant reduction in the final cost. It was not until the end of the 1980s that the first electronically-controlled pumps appeared.

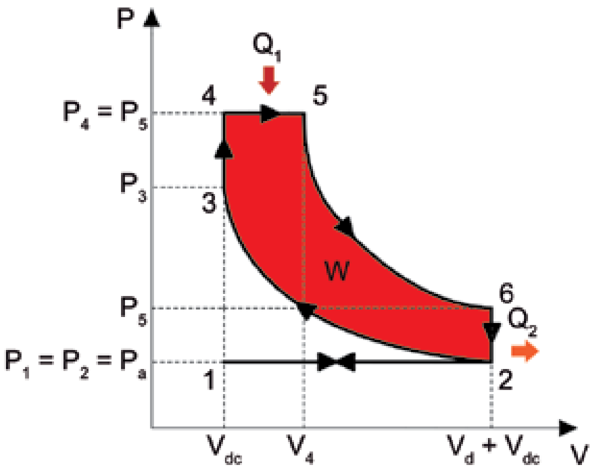
To overcome the limitations of compact distributor pumps, two "old" concepts were revived: the pump-injector, developed together by the Volkswagen and Bosch groups, introduced in 1994 (although its application in mass-production did not arrive until 1998), and the Common Rail, developed by Fiat together with Magneti Marelli, although it was ultimately mass produced by Bosch.

The rapid evolution of electronic control systems for diesel engines has increased performance, which has further highlighted their lower fuel consumption and higher cost effectiveness. After the summit and signing of the Kyoto Protocol for the reduction of greenhouse gases, the purchase of diesel vehicles was incentivized due to their lower production of CO_2 in comparison with vehicles equipped with petrol engines.

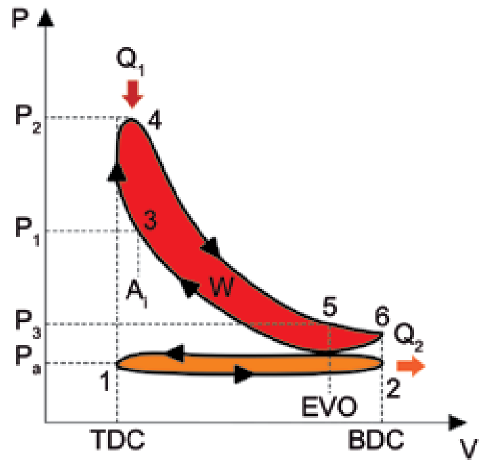
RECIPROCATING DIESEL ENGINE

Theoretical and real cycles

The famous 4 strokes of the diesel engine are illustrated in the following operating diagrams.



Theoretical cycle



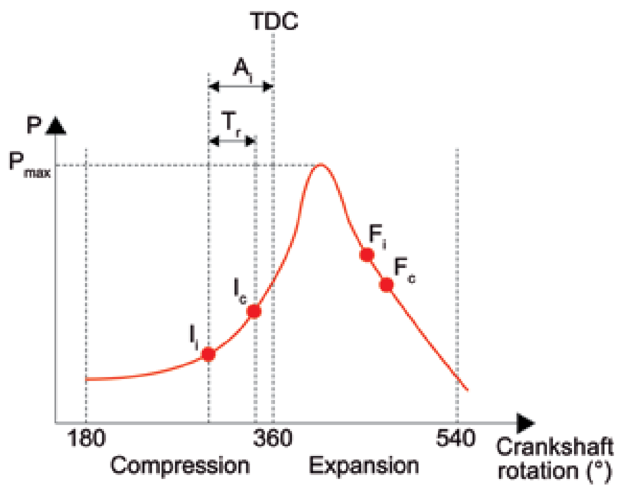
Real cycle

Intake phase (1-2): In the theoretical cycle, the start of the down stroke of the piston, along with the opening of the intake valve, allows atmospheric air to enter, which fills the expanding volume of the cylinder to the BDC (Bottom Dead Centre), at which point the valve closes. In the real cycle, the efficacy of the filling of the cylinder is affected by the engine's operating speed, its resonant frequency and the temperature of the atmospheric air.

Compression phase (2-3): In the theoretical cycle, the up stroke of the piston with the valves closed reduces the volume of the cylinder. The increase in pressure causes the gas (atmospheric air) to heat up until it reaches the TDC (Top Dead Centre), at which point the temperature is much higher than necessary to ignite the fuel. This compression of the air requires the input of energy. In the real cycle, the pressure and temperature caused by compression are affected by the operating speed of the engine and the temperature of the walls of the cylinder (cooling system).

Compression and expansion phase (3-4-5): In the theoretical cycle, the fuel is injected into the cylinder (3-4) and comes into contact with the compressed air, which causes the fuel to heat up and ignite. Combustion provides the necessary heat (Q1) to maintain the pressure achieved previously as long as the fuel supply lasts. The high pressure forcefully pushes the piston downward, where the crankshaft-connecting rod assembly transforms it into rotational torque. When injection stops, the pressure and temperature of the gases drop (5-6). In this stage, the energy added during the compression is recovered, in addition to the energy obtained in the form of heat from the combustion that is transformed into mechanical energy.

The way in which the fuel is injected and the development of combustion are the factors that have the most impact on the real execution of the diesel cycle. The power stroke is sub-divided into three clearly differentiated periods: the ignition delay, the delay time (Tr) and ignition.



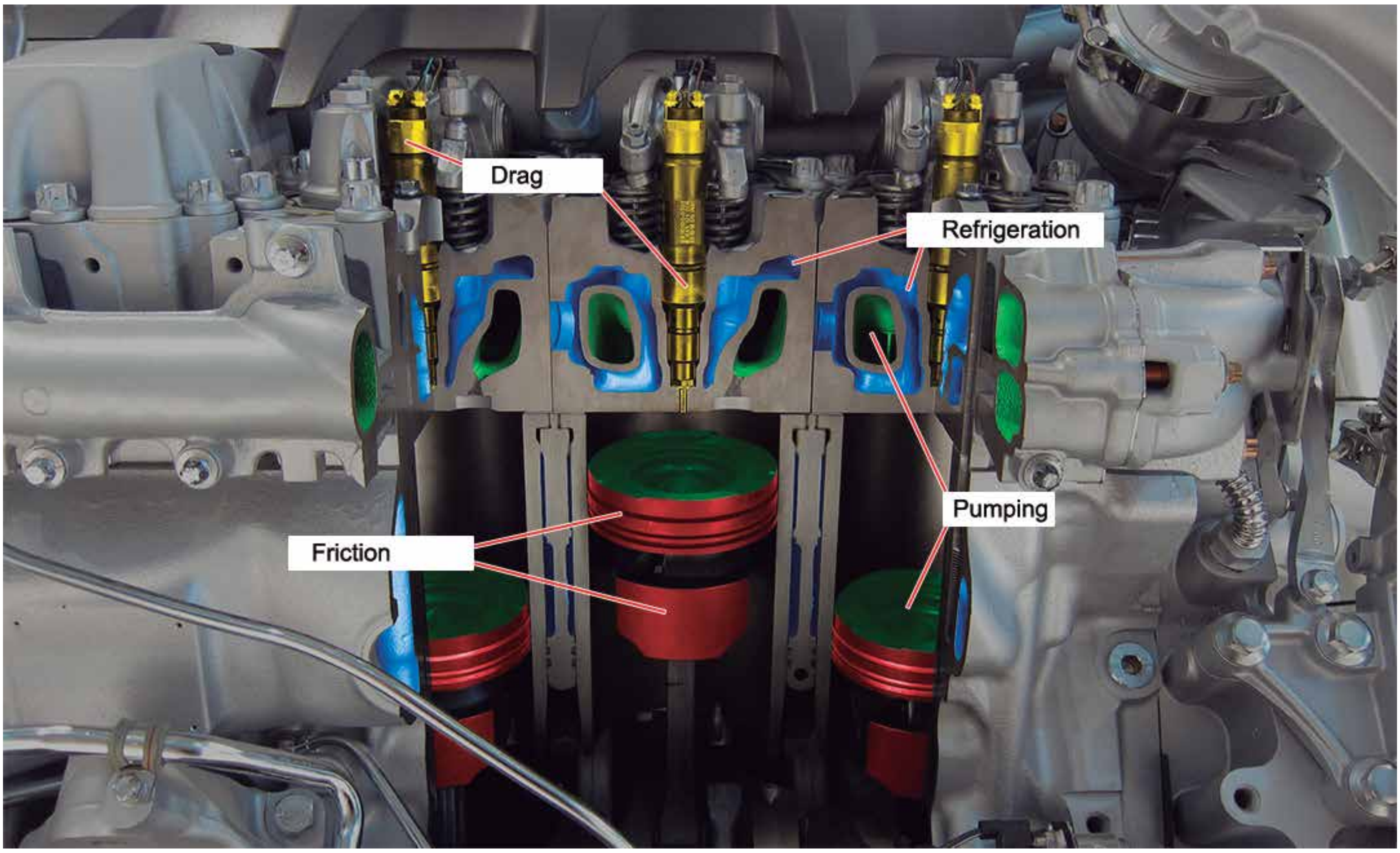
Exhaust phase (6-2-1): The opening of the exhaust valve, in the theoretical cycle, allows the cylinder to empty due to the decreased volume caused by the up stroke of the piston. The expulsion of the exhaust gases results in a loss of heat when they leave the cylinder. After the exhaust time, the cycle repeats continuously, so that positive mechanical work is obtained in one out of every four strokes.

In the real cycle, when the power stroke ends, part of the gases are automatically carried to the outside through the exhaust valve by the residual pressure still present at the end of the combustion time, which means that part of the heat obtained from the fuel is lost through the exhaust. The exhaust valve opening (EVO) before the BDC is almost mandatory to achieve effective emptying of the cylinder, because the advance in the exhaust valve closing (EVC) is inevitable for mechanical reasons.

Energy losses of the engine

In addition to the defects in the real diesel cycle, the drawbacks involved in its practical execution in reciprocating engines must also be taken into account. The physical impositions of the mechanical design, the thermal behaviour of the materials and operation at variable speeds result in losses that affect the final performance. This means that only part of the total thermal energy released by the combustion is transformed into mechanical energy that is available to carry out the work of propelling the vehicle or any other work.

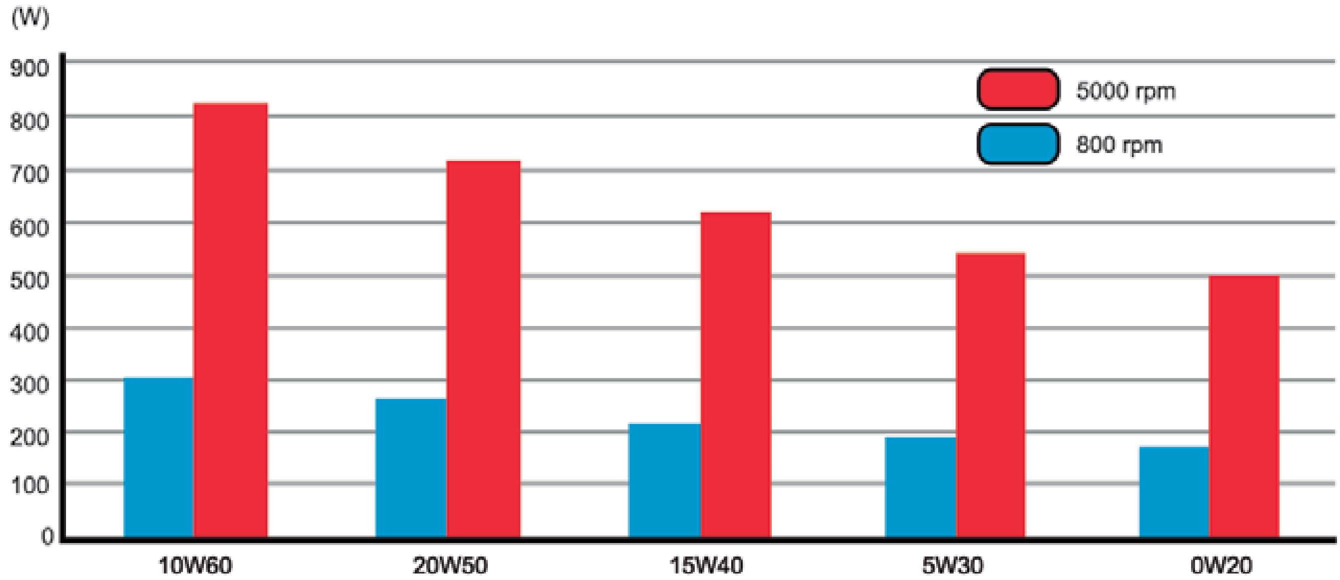
The most significant energy losses in diesel engines are caused by:



Refrigeration: The metals that make up engines are "unstable" at the temperature that causes the combustion of the diesel fuel (there is a risk of expansion and melting), so a cooling system is required. The heat discharged by the cooling system does not increase the temperature and pressure of the gases, so it is therefore a loss that is generated mainly in the combustion-expansion phase, and to a lesser extent in the compression phase.

Pumping: The opening cross-section of the valves is limited by the design of the cylinders and cams, and may restrict the cylinder's filling and emptying flow at some points. The density of the intake air and the gases generated by the combustion are determining factors in this regard. When the variation of the volume of the cylinder in the intake and exhaust stages is greater than the gas flow permitted by the valves, forces are generated on the piston head opposite to its direction of motion, creating resistance that must be overcome by the addition of mechanical energy.

Friction: The rubbing and friction forces between elements that work while in contact with each other are inevitable in some of the engine components that operate without lubrication. Even in the case of elements that are lubricated, the viscosity of the lubricant generates forces against the movement whose values increase as the operating speed increases.



Particularly in the case of the piston rings, due to their high speed of movement, and on the connecting rod and main bearings, due to the large contact area, losses due to friction may be considerable. Timing belt and serpentine belt drive movement also generates a certain amount of friction.

Hydrocarbon combustion

The heat required to increase or maintain the pressure inside the engine cylinders is obtained in diesel engines from the oxidation of the different hydrocarbons present in the diesel as a result of its reaction with the oxygen in the atmospheric air (O_2).

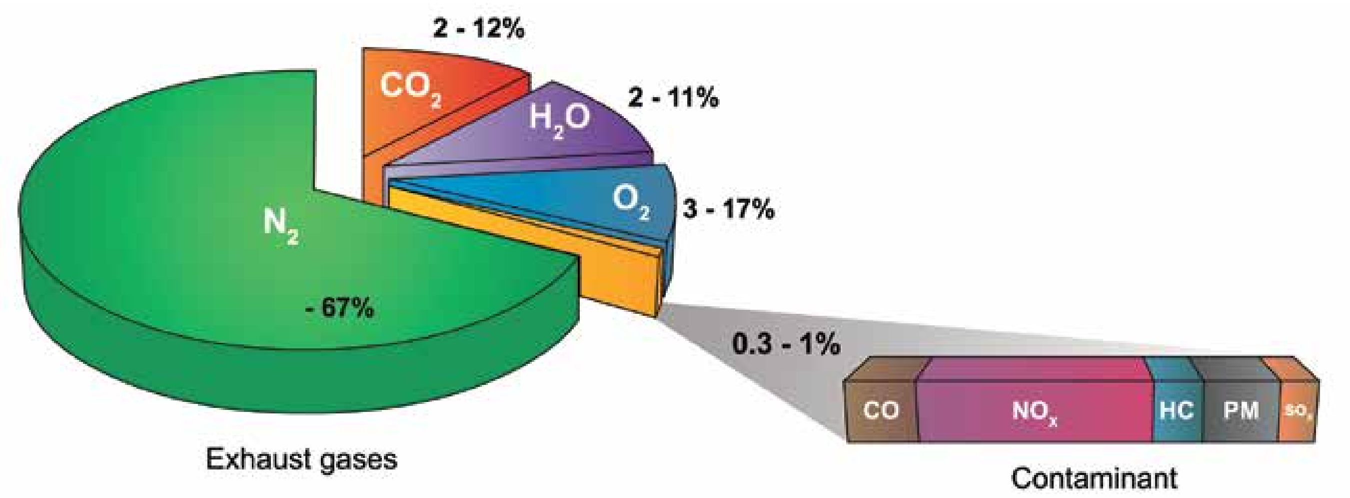
Later, the combination of oxygen with carbon produces carbon dioxide CO_2, and its combination with hydrogen forms water (H_2O) when the chemical reaction is complete and perfect.

For this to occur, **two basic conditions** must be fulfilled, which, despite being chemically simple, are not always present in fast engines.

1. **Proportionality between reactant elements:** A diesel engine requires 14.5 grams of air for each gram of fuel (14.5:1) in order to completely oxidise the diesel fuel (stoichiometric ratio). Using this proportion, it is possible to calculate the heat energy that is released and the mass of the resulting products at the end of the reaction.
2. **Sufficient temperature**: In order for the oxidation reaction to be triggered, an initial addition of energy is required to raise the temperature of the hydrocarbons (CxHx) above their ignition temperature. The liquid diesel must change to a gaseous state, the point at which the forces of attraction between its molecules disappear and the hydrocarbons can mix with the air (oxygen). The impossibility of achieving perfect and homogeneous combustion means that diesel engines operate with an excess of air; even so, in certain operating conditions, partial (incomplete) combustion occurs, which, in addition to reducing the output, generates carbon monoxide (CO), light hydrocarbons (HCs) and particulate matter.

Diesel pollution

The "real" diesel operating cycle differs significantly from the "theoretical" cycle as a result of the state change of the fuel and heat loss, among other factors. The practical execution of the diesel operating cycle, particularly in the combustion stroke, also adds defects associated with the limitations imposed by the injection system, the high operating speed and some chemical reactions not expected initially. Even working with excess air, the oxidation of hydrocarbons may be imperfect in some zones, which, in addition to reducing the heat efficiency of the process, generates carbon monoxide (CO), particulate matter (PM) and hydrocarbons (HC) in a gaseous state in the exhaust gases.



In addition, the presence of certain substances in the combustion chamber that "theoretically" do not participate in the combustion reaction makes it possible for parasitic chemical reactions to occur in parallel, with their corresponding end products (NOx and SOx). For all of these reasons, the exhaust gases of today's fast diesel engines contain a small fraction of pollutant substances, which in general do not exceed 1% of the total, with the remaining part being carbon dioxide (CO_2) and water vapour (H_2O) generated by proper and complete combustion of the hydrocarbons, plus the excess air that did not participate in the reaction (N_2 and O_2).

The relative proportion between non-pollutant gases depends mainly on the load state of the engine and the will of the driver (speed /load), which determine the amount of fuel that is injected and its proportion with respect to the mass of air that fills the cylinders. The production of pollutant substances is due to a greater extent to the conditions under which the combustion takes place, clearly conditioned by the variations in temperature, pressure and swirl inside the combustion chamber caused by the operation under variable loads and speeds, and the limitations characteristic of the fuel injection system.

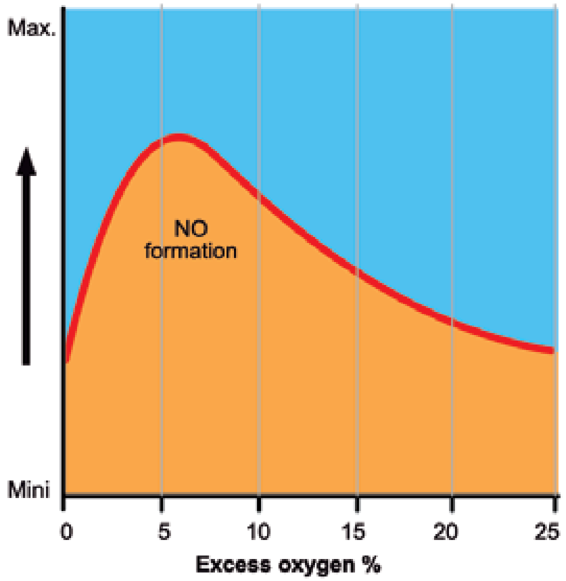
Carbon dioxide (CO_2)

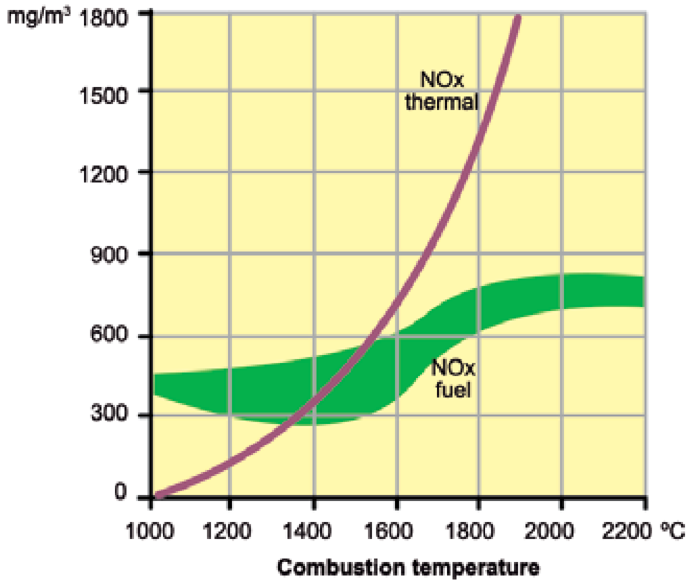
Carbon dioxide is a gas, whose molecules are comprised of two oxygen atoms and one carbon atom. It is produced by the complete combustion of carbon and the higher its concentration, the better the combustion. This is not harmful to living organisms, but an increase of its concentration in the atmosphere may cause large-scale climate change due to the greenhouse effect. 41% of the anthropogenic (caused by human activity) greenhouse gases that are emitted each year can be attributed directly to transportation, the largest part of which is propelled by diesel engines.

Nitrogen oxides (NOx)

The nitrogen oxides (NO and NO_2) that are generated during combustion represent approximately 50% of the total pollutant emissions of modern diesel engines and in recent years have become their main drawback.

In sufficient concentration, it reduces the proportion of O_2 in the air and damages moist tissues (particularly the respiratory system), and may cause asphyxiation depending on the concentration. Nitrogen monoxide is a gas with low toxicity at the concentration at which it is found in the atmosphere, while nitrogen dioxide is a gas that is a strong irritant and asphyxiant. "The combination of NO_2 with the moisture in the air forms nitric and nitrous acids, which affect living organisms in the form of acid rain, alter the mineral composition of soil and erode materials and installations.





Hydrocarbons (HC)

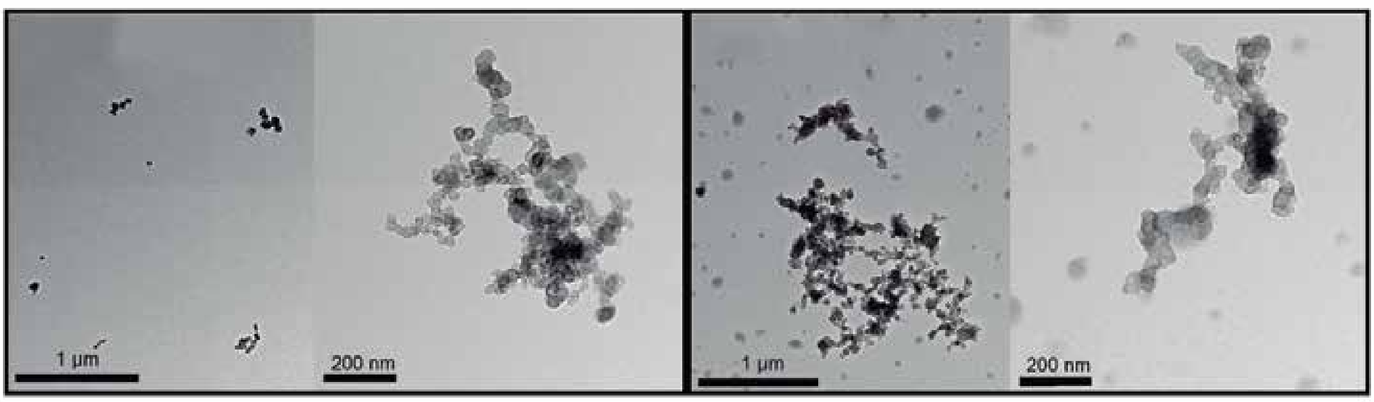
Hydrocarbon emissions are the result of unburned fuel, as a result of incomplete combustion. Hydrocarbons are generated in different combinations depending on the type of fuel and act in different ways on the body. Some of the hydrocarbons emitted to the atmosphere have minor effects on health such as irritation to sensory organs, and others such as benzene may be much more damaging and dangerous since they are carcinogenic.

Carbon monoxide (CO)

The lack of oxygen in combustion results in incomplete combustion and the formation of CO instead of CO_2. The appearance of higher concentrations of carbon monoxide in exhaust gases indicates the existence of a rich initial mixture or a lack of oxygen. Carbon monoxide is an odourless, colourless, flammable and highly toxic gas that may cause death when inhaled in high concentrations. In high concentrations and long exposure times it may cause an irreversible transformation of haemoglobin in the blood, which is a molecule in charge of transporting the oxygen from the lungs to the cells in the body. Concentrations of CO higher than 0.3% in volume are deadly.

Particulate matter (PM)

These are emissions that are easily perceived due to the dense black smoke that they generate. They are produced during incomplete fuel-rich combustion (diesel, CH) when the engine is running under full load and at low and medium speed. This occurs when a large quantity of fuel is injected and part of this fuel does not encounter a sufficient volume of oxygen around it to complete the oxidation, which generates long chains of partially oxidized hydrocarbons after combustion, which tend to regroup to form soot (carbon).



The soot is made up of small pulverized impure carbon particles (up to 100 nanometres) with a colour darker than ash. Since they are so small, when they are inhaled, they enter the bloodstream and are transported to cells along with nutrients, which generates alterations in cells that can later lead to cancer. Other effects on health when particles remain in suspension in the atmosphere are allergies, asthma and respiratory problems.

Sulphur dioxide (SO_2)

This originates from the sulphur contained in the fuel (diesel), due to the fact that it is a natural element of crude oil. The concentration of sulphur can vary depending on the quality of the type of crude. The heavier the fuel, the higher the sulphur content and the lower the quality, because the sulphur does not participate in the combustion to generate energy.

It is a colourless gas with a pungent odour that generates sulphur dioxide as a by-product after combustion. This is an element that is harmful to the environment because in contact with the air, it oxidises and transforms into sulphate and sulphuric acid suspended in small particles, which ultimately precipitate causing acid rain. SO_2 causes irritation and dysfunction in the respiratory system (lungs and nasal passages) in people. Sulphur also quickly degrades the oil and reduces the efficiency of the particulate filter, contributing to an increase in the soot emissions from the engine. To reduce SO_2 emissions, fuel manufacturers are required to refine the crude oil to minimize the sulphur concentration.

EUROPEAN REGULATIONS

In the European Union, there is legislation that regulates the limits of emissions produced by internal combustion engines through a series of standards and directives, which are mandatory for all new vehicles sold in the member states. Emissions of carbon monoxide (CO). nitrogen oxides (NOx), hydrocarbons (HC) and soot particles (PM), are regulated for most vehicles and different standards are applied depending on their characteristics.

One offshoot of the aforementioned legislation is the CAFE programme (Clean Air For Europe), designed to improve air quality with the obligation to reduce the emissions generated by the transport sector through standards and directives. Over the years, these standards and directives have become increasingly stringent as a result of increasing environmental contamination; they are known as EURO 1, EURO 2, EURO 3, EURO 4, EURO 5 and EURO 6, each one more stringent than the last.

Diesel						
Type	Date	CO	HC	HC + NO_x	NO_x	PM
Euro 1	July 1992	2.72	-	0.97	-	0.14
Euro 2	January 1996	1	-	0.7 (*) - 0.9 (**)	-	0.08 (*) – 0.10 (**)
Euro 3	January 2000	0.64	-	0.56	0.50	0.050
Euro 4	January 2005	0.50	-	0.30	0.23	0.025
Euro 5	September 2009	0.50	-	0.23	0.18	0.005
Euro 6	September 2014	0.50	-	0.17	0.08	0.0045
* Indirect-injection engine ** Direct-injection engine						

The transfer of the evolution of the standards and gas tests for type approval, which are becoming more and more complete and restrictive, to mandatory vehicle inspections in each country is not direct. Although there is a certain relationship in the maximum permitted values of CO, not all of the pollutant substances covered in the standard are subjected to periodic controls, and different systems and measurement/evaluation methods are also used.

In order to ensure proper compliance with the anti-pollution standards, the EOBD (European On Board Diagnostics) standard was created. This is a diagnostic system that is incorporated into the vehicle to monitor the vehicle's sensors and record the measurement values, memorize malfunctions in the engine management components and view the parameters related to the pollution-control systems.

The reduction of pollutant emissions imposed in the standards is only possible in two ways:

- Avoiding their production.
- Or forcing their chemical transformation into non-pollutant substances or compounds.

REDUCTION OF POLLUTANT SUBSTANCES IN THE COMBUSTION PROCESS

Evolution of diesel engines

The growing demand for diesel vehicles in the European market to the detriment of petrol vehicles, together with the increasingly stringent type approval standards, have spurred the significant technical evolution that these engines have experienced in the last three decades. There is a need to increase the energy output of the engine while at the same time reducing fuel consumption and directly reducing the CO_2 produced. To do this, efforts have been focused on two main aspects: combustion control and reduction of direct and indirect energy losses.

The principal solutions that have been adopted are:

- **Supercharging the engine:** Using a turbocharger with a relief valve, variable geometry or two-stage systems. There are currently tri-turbo engine designs, although their presence in the market is limited.

- **Regulation of the start of the injection and the quantity of fuel injected:** Using electronically-controlled injection and injectors with faster and faster response and more precise dosing, working with injection pressures that are progressively higher and injectors with a larger number of injection orifices that are smaller, injecting directly in the centre of the combustion chamber and discontinuous supply of fuel.

- **Control of the swirl in the combustion chamber:** With multiple intake lines and variable gas flow cross-sections.

- **Electronically-managed adjustable cooling.** System performance optimized based on the engine load, the ambient temperature and the temperature of the exhaust gases, to avoid overcooling the combustion chamber. Active cooling of the piston heads by electronically-controlled oil stream.

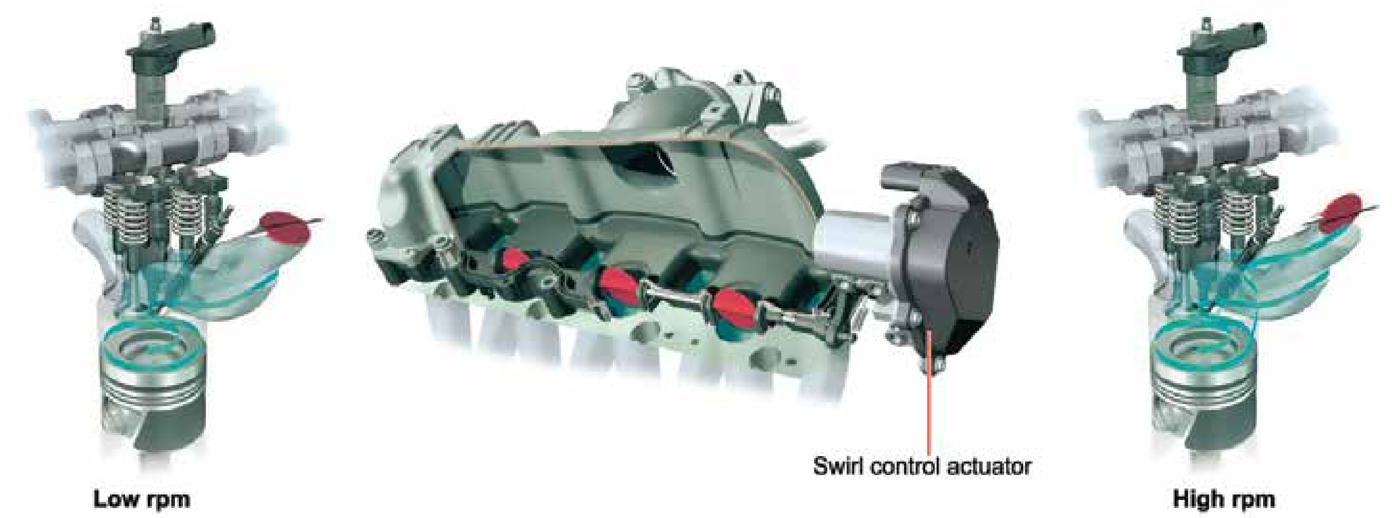
- **Reduction of friction in the components of the reciprocating engine train and timing:** Rings and cylinders made of specific materials, timing by chain or belt in an oil bath, camshafts on anti-friction bushings and pistons with low-friction coatings.

- **Low-viscosity lubricants and electronically-regulated lubrication pressure:** Variable oil flow/pressure based on the engine's operating conditions.

- **Charge control of the smart alternator:** Generator output regulated electronically based on the charge status of the battery and the engine torque required by the driver.

- **Reduction of electrical consumption of the engine control system:** Sensors and actuators that require lower voltage and current to work are used. The transmission of signals in digital format increases the precision and reliability of the information while at the same time reducing electricity consumption.

- **Active heating of the engine:** Reduction of the time needed to reach the optimum service temperature. The stopping of the cooling flow and activation of spark plugs after a cold start facilitate the rapid heating of the combustion chamber, reducing fuel consumption.



NOx reduction

The quantity of oxygen and nitrogen in the combustion chamber is comparatively greater in a supercharged diesel engine than in a naturally aspirated engine with the same cylinder volume and consequently, the quantity of NOx emissions is also greater. However, the CO and HC emissions are lower. The solution adopted by the manufacturers to reduce, as much as possible, the formation of NOx in these circumstances without decreasing thermal efficiency, consists of redirecting part of the exhaust gases back to the engine's air intake circuit using a technique called EGR (exhaust gas recirculation).

This has the following advantages:

- It reduces cooling caused by charge renewal.
- It reduces the quantity of oxygen with respect to nitrogen while at the same time enriching the mixture.
- It promotes the dispersion, penetration and gasification of the fuel.
- It slows the combustion process.
- It reduces emissions of HCs and CO when the load is very low (idle).

At the same time, it also has the following drawbacks:

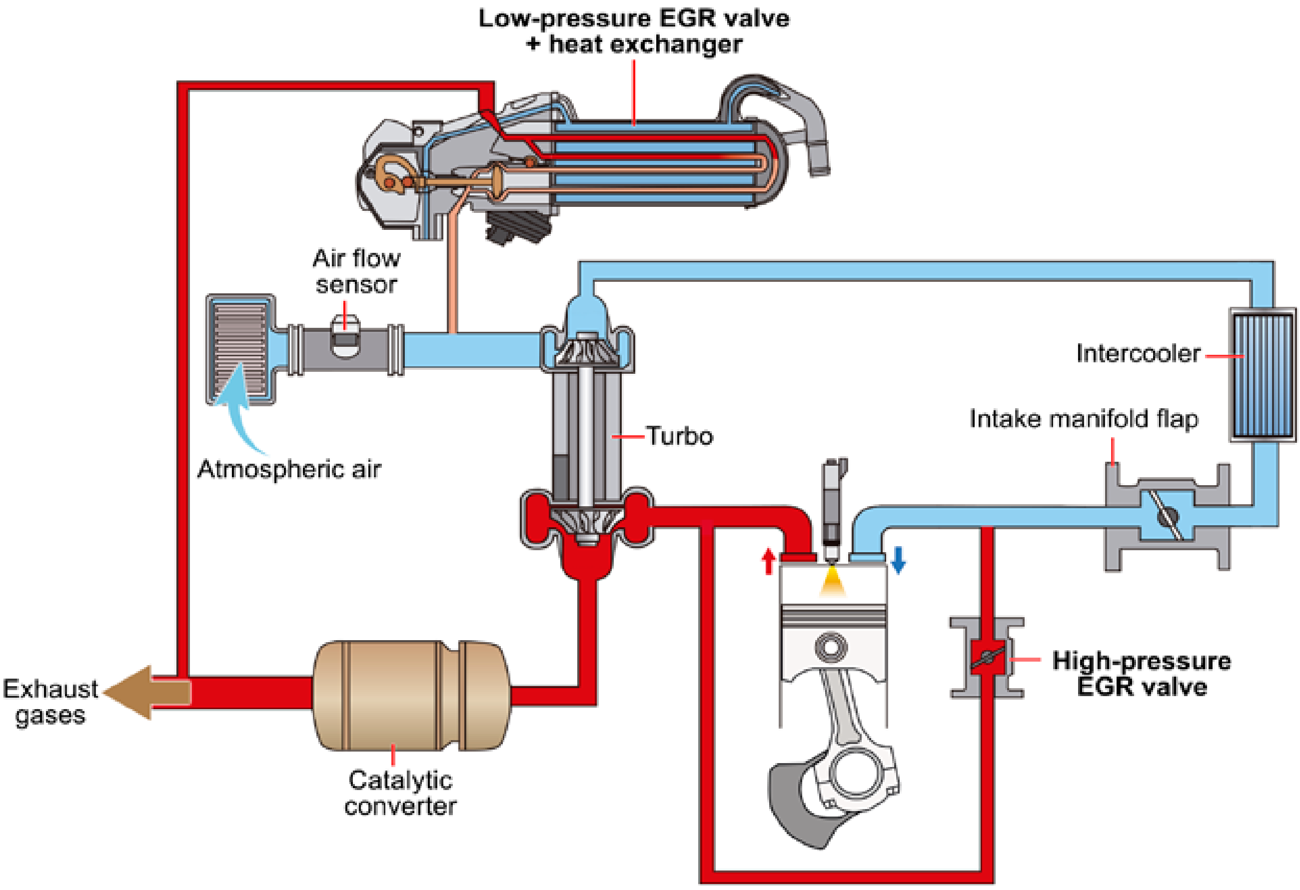
- The intake circuit becomes dirty as a result of the soot, which complicates the filling of the cylinders.
- It increases the production of particulates due to the lack of oxygen and low temperature.

Evolution of the EGR system

The system is aimed at improving its precision and increasing the operating range. The early systems only operated during idling while the current systems remain active unless working at a very high load. The mass of recirculated gases is also used during the engine warm-up phase to reach the service temperature as quickly as possible. The flow of recirculated gases in EGR systems reduces the flow of gases over the turbocharger's exhaust turbine reducing its blowing capacity at low speeds and the response speed.

In double EGR systems, the low-pressure exhaust gases are sent to the intake side of the turbocharger, ensuring the necessary quantity for charging, with a minimal impact on the performance of the turbocharger. The kinetic energy that they provide to the rotor as they pass through the exhaust turbine is the same as the energy that they pick up on the intake and compression side. The redirection of the exhaust gases, after processing by the pollution systems (low-pressure circuit), prevents the presence of particulate matter (PM) in the charge gas and reduces the oxygen content even more. Part of the O_2 that does not participate in combustion has been combined with other elements in the catalytic converter (transformation of CO into CO_2 and HCs into CO_2 + H_2O), which means that its concentration is even lower.

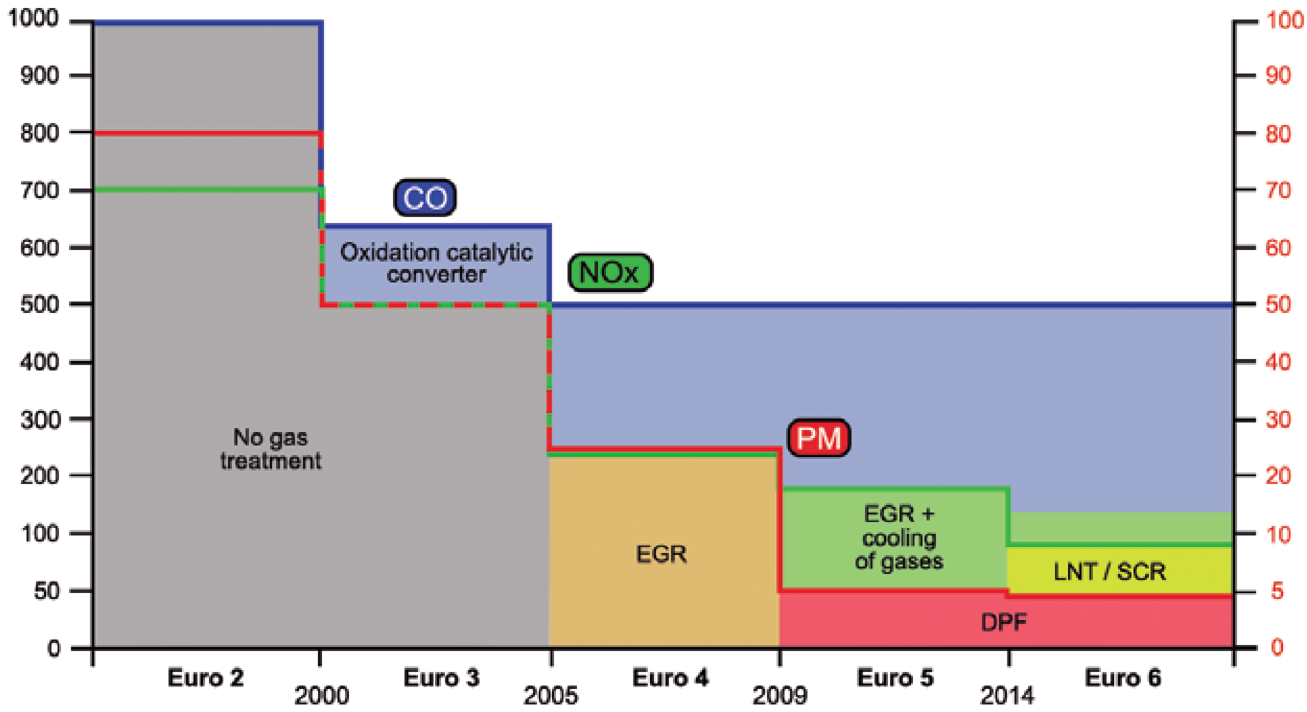
In order to reduce nitrogen oxides even more, the exhaust gas is cooled, with the engine hot, by passing it through a water-cooled exhaust gas recirculation radiator.



COMPOSITION OF THE EXHAUST GASES

The technical solutions that manufacturers are attempting to improve combustion are not sufficient to comply with the restrictions required in the type approval tests. For years, to obtain type approval, an effort must be made to convert the pollutant substances generated by the combustion process into substances that are not harmful to health or the environment, using reduction or chemical transformation systems.

The different physical and chemical nature of the pollutants produced by diesel engines means that both passive and active systems specifically designed to reduce each one of the pollutants are required to transform them.

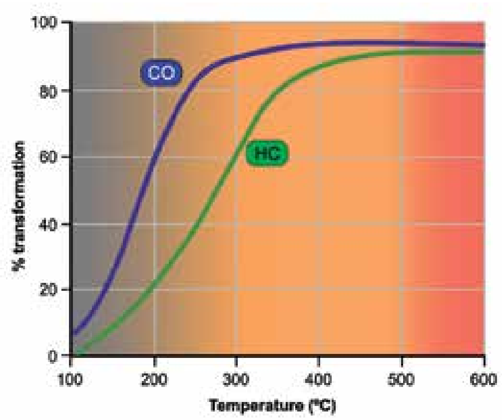


The development, application or evolution of the anti-pollution systems that currently exist corresponds in many cases to the application of new standards, either due to the inclusion of tests for substances that were not previously considered, or due to the large reduction required of substances that are already included in the standards.

The systems for transforming and treating the exhaust gases that are used are the following, in chronological order of development:

Oxidation catalyst (DOC)

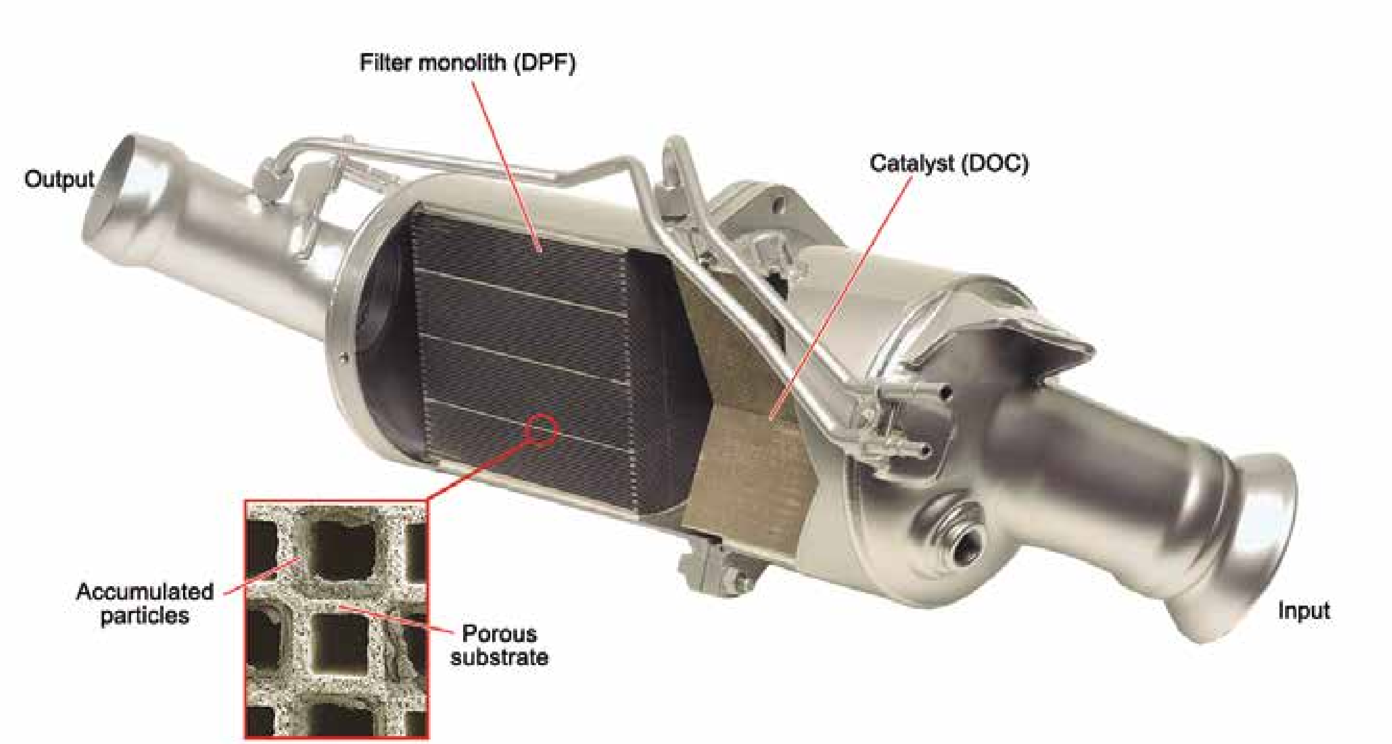
The pollutant gases produced by combustion, generally CO and HC, undergo a chemical transformation in the oxidation catalyst, incorporated into the diesel engines. This catalyst oxidises the carbon monoxide and unburned hydrocarbons, transforming them into carbon dioxide (CO_2) and water (H_2O). At the catalyst intake, in addition to the CO and HC gases, NOx, whose quantity can be reduced through an exhaust gas recirculation system, is also present.



The oxidation catalyst is made up of a stainless steel box with a ceramic monolith inside. The ceramic body has a network of cells whose surfaces are coated with a layer of aluminium oxide vaporized with platinum and palladium. When the exhaust gas crosses the cells, they heat up the catalytic converter, starting the conversion of pollutants into inert substances. Noble metals oxidise exhaust gases, lowering the concentration of carbon monoxide and of unburnt hydrocarbons.

The oxidation catalytic converter is mounted as close as possible to the engine, so that it can quickly reach the temperature required for efficiently carrying out its function. The chemical reaction to oxidise carbon dioxide and hydrocarbons is most efficient at temperatures higher than 200 °C.

DPF particulate filter



Its purpose is to filter and store the soot particles that are generated during the engine's combustion process. It also ensures the combustion of the soot particles during the regeneration phase.

The particulate filter consists of a ceramic body made of silicon carbide that is housed in a metal casing. The exhaust gas circulates inside the filter in small parallel channels that are closed alternatively. Their walls are porous to the exhaust gas, but not to soot particulates, which are retained. The walls of the ceramic body are coated with a combination of platinum and cerium oxide. When the gases come in contact with the platinum coating, they form nitrogen dioxide (>NO_2), which causes oxidation of the soot particulates when the temperature rises above 350 ºC, thus producing a passive regeneration of the filter.

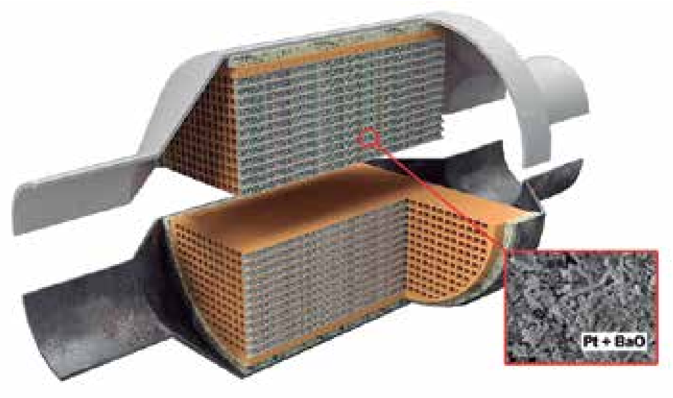
The cerium oxide that is present in the coating accelerates the thermal regeneration with oxygen (O_2) at a temperature above 580° C. This occurs when the regeneration is activated by the engine control unit. To activate regeneration, the measurement read by the differential pressure sensor is taken into account. This sensor measures the intake and outlet pressure of the particulate filter and sends the information to the engine control unit where the degree of saturation of the particulate filter is determined.

NOx LNT reduction systems

This is an accumulator/catalyst system that traps the NOx. It is made up of an open square grid structure with a coating of platinum and barium oxide, which is installed after the DOC and generally before the DPF.

During periods of lean mixture (λ>1), the platinum attracts the NOx that is formed during combustion and facilitates the oxidation of the NO by combining it with the excess O_2 from the combustion to form NO_2. Due to physical proximity, the barium oxide (BaO) traps the NOx to form nitrites Ba(NO3)2, so this phase is called absorption.

The engine control unit evaluates the proportion of NOx after the accumulator, through a NOx sensor. The high proportion of NOx indicates the saturation of the filter, so it has to be restored by transforming the retained NOx into N_2 and H_2O. For this reason, the engine control unit briefly enriches the fuel/air proportion until the instantaneous transformation capacity of the DOC is exceeded. The presence of HCs and CO in the accumulator, together with the low presence of O_2 causes the decomposition of the nitrites and the release of N_2 when its oxygen combines with the CO to form CO_2 or with the carbon and hydrogen of the HCs forming CO_2 and H_2O. This allows the barium to return to its original state (BaO), and recover its NOx absorption and storage capacity.
During the reduction phase, the production of particulate matter, CO and hydrocarbons during combustion increases momentarily, which also results in an increase in fuel consumption. The performance of the LNT catalyst is at a maximum between 150 and 450ºC and decreases, particularly in the DPF filter regeneration phases due to the high temperature of the exhaust gases that is necessary for prolonged periods of time.



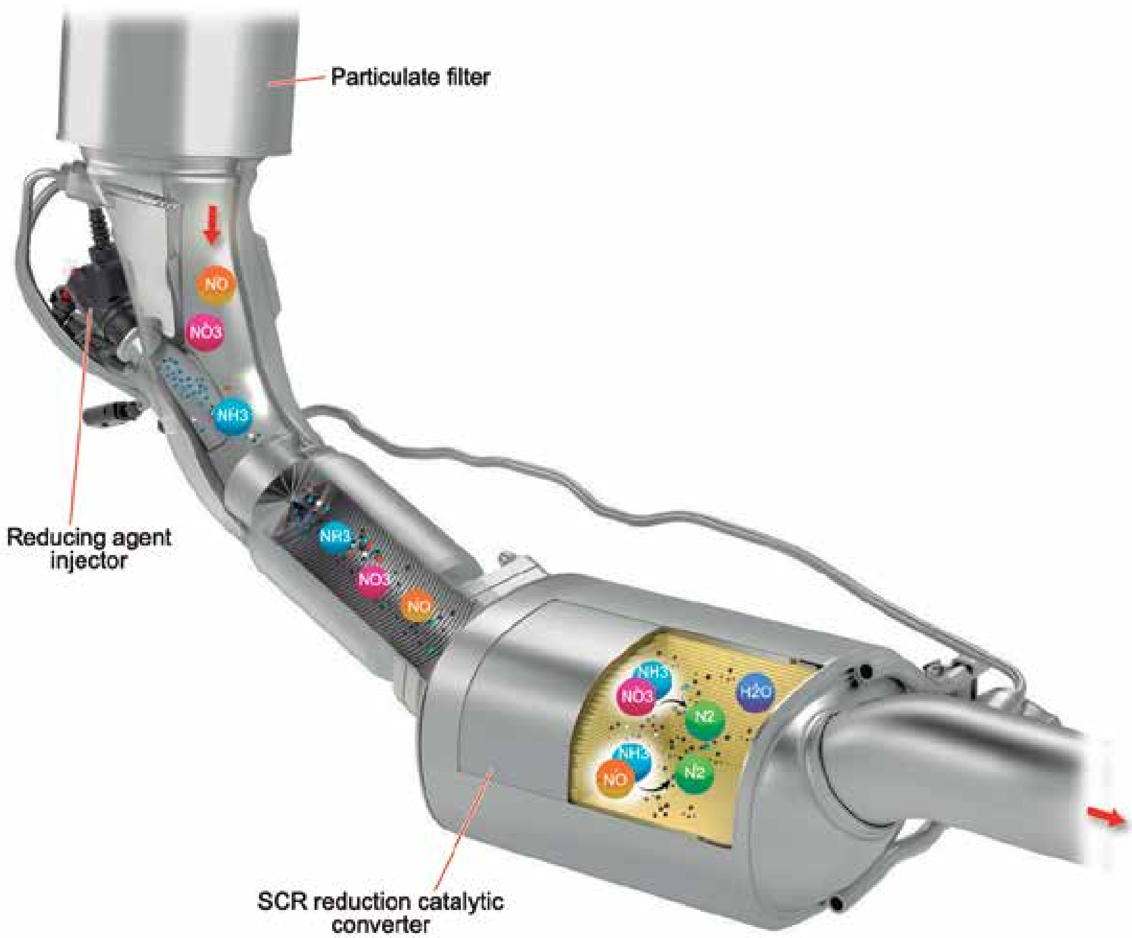
NOx SCR systems

The system described above increases the production of particulate matter (PM) and its accumulation in the DPF filter, which involves more frequent regenerations and increases fuel consumption. The other alternative used by most light vehicle manufacturers is based on SCR (Selective Catalytic Reduction) technology.

The principal characteristic of this system is the additional use of the reducing agent AdBlue to function. The necessary chemical elements (AdBlue) are injected into the flow of exhaust gases through an injector to achieve the continuous transformation of the NOx into N_2 and H_2O. The AdBlue reducing agent is transformed into ammonia (NH_3) by thermolysis, in other words, a chemical reaction conditioned by heat and by hydrolysis (a chemical reaction conditioned by water).

- Thermolysis: (NH2)2CO → NH_3 + NHCO
- Hydrolysis: HNCO + H_2O → NH_3 + CO_2

This achieves a reduction of between 90 and 95% of the NOx produced by the engine, depending on the temperature of the exhaust gases. SCR systems are mainly made up of a specific catalyst, a hydraulic circuit and the sensor and actuator elements that are needed to regulate the quantity of additive injected into the exhaust based on the concentration of NOx.



Eure!Car® techn

CERTIFIED MASTERCLASSES

aut

bilsteingroup® febi bilstein SWAG BLUE PRINT

BOSCH

brembo

CHAMPION

Gates

HELLA

KYB Our Precision, Your Advantage

MAHLE

Nissens DELIVERING THE DIFFERENCE

PHILIPS

SCHAEFFLER

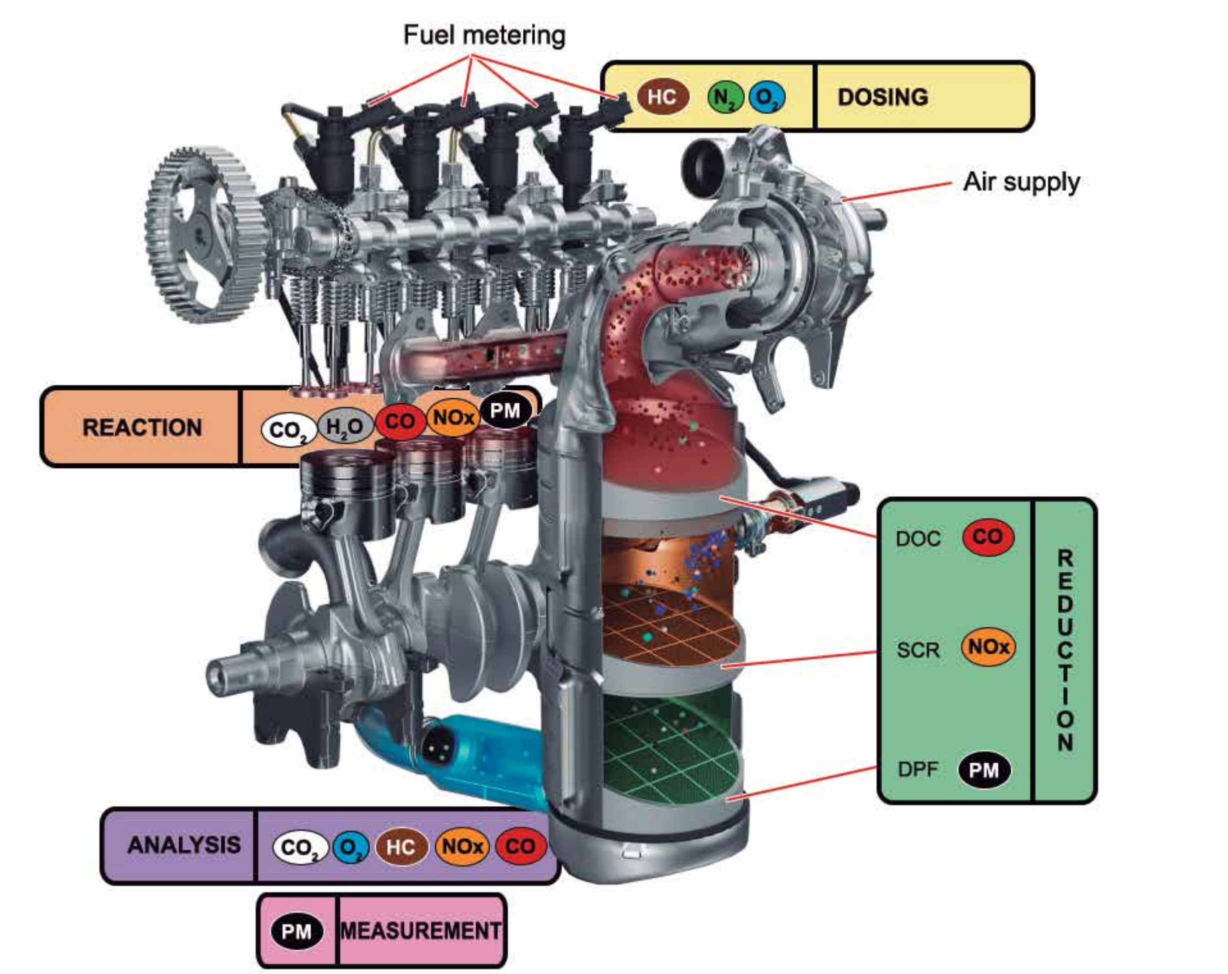
SKF

ical education for
professional
omotive repairers
www.eurecar.org
Continental
DENSO
EXIDE TECHNOLOGIES
FERODO
MANN FILTER
metelligroup AUTOMOTIVE PASSION
MONROE
Niterra
SNR Brand of NTN corporation
TRW
Valeo
VARTA
ZF

ANALYSIS OF DIESEL GASES

Control of exhaust emissions in diesel engines

The main purpose of gas analysis in modern diesel engines is to monitor the effectiveness of the different anti-pollution control systems, whose poor functioning may or may not affect the normal performance of the engine and consequently be the direct cause of different malfunctions.



The maximum acceptable values of pollutant substances for each vehicle logically depend on the anti-pollution systems installed in the vehicle and the required type approval standard. It must also be kept in mind that the reduction capacity in some of them is not absolute and that their effectiveness depends in many cases on the operating temperature and other external factors.

The work of the active anti-pollution systems also depends on correct regulation by the control unit, a function which must be checked using diagnostic instruments. Unlike petrol engines, in which the final composition of the exhaust gases is practically the same throughout the operating range, regardless of the load; in diesel engines, it must be carried out under different operating conditions and taking NOx emissions into account.

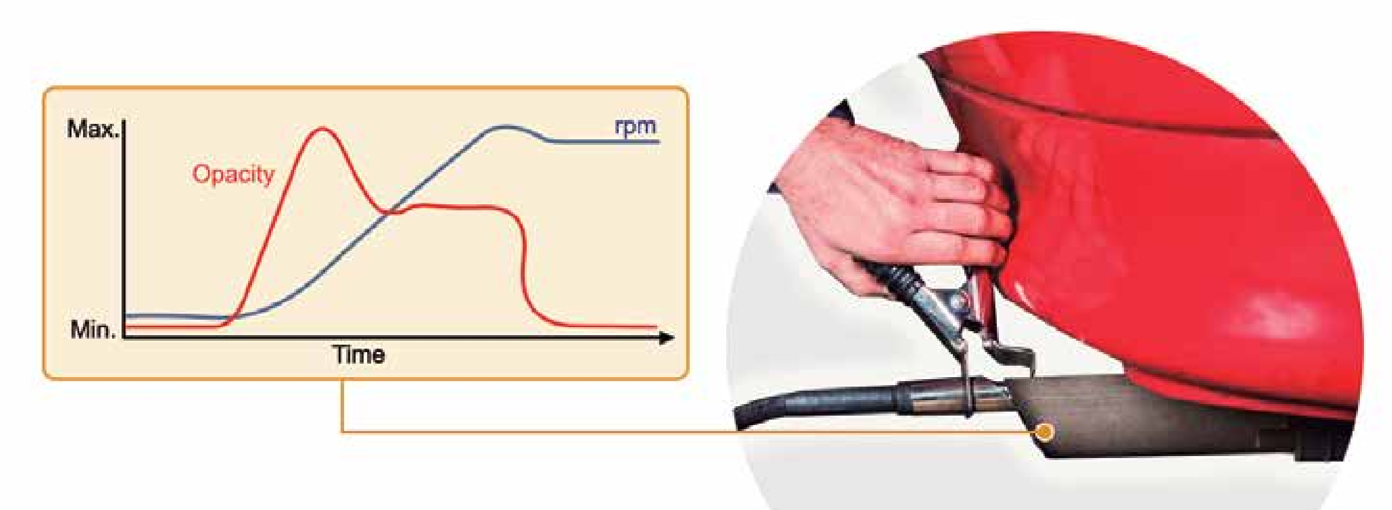
The formation of particulate matter, most of which is invisible, must also be taken into account as a step prior to the measurement of the gases. In addition to the mandatory control of the opacity of fumes or the verification of the efficacy of the particulate-control systems, the excessive production of particulates is a clear indicator of dosing or combustion issues. The formation of particulate matter modifies the chemical result of combustion, reduces production of CO_2 and increases the excess quantity of O_2, which facilitates the formation of NOx if the temperature is high enough.

Opacity measurement equipment

The possible production of both gases as well as particulate matter during the combustion reaction, characteristic of diesel engines, requires the use of two independent measurement instruments to evaluate them.
For years, the quantity of particulate matter has been measured using opacimeters with the engine in the acceleration phase from minimum speed up to the maximum rpm limit. This way, the mass of air that enters the cylinder in each work cycle increases up to a certain speed (maximum filling efficiency and maximum torque) and decreases progressively after that point. Under these conditions,

the mass of fuel injected in each cycle is regulated at the maximum quantity during acceleration and must be reduced later to limit the engine speed.

The possibility of the formation of particulate matter if the air fill or dosing of fuel are incorrect or if there are combustion problems is greatest under these circumstances, since the check is carried out under variable speeds, with extreme enrichment, and under flow reduction at high speed.



Most of the opacimeters currently available on the market work in combination with a desktop or laptop personal computer, which performs the calculation functions and displays the results of the measurements.

5-gas analysis

The systems for the measurement of pollutant substances that are used during type approval tests measure absolute and cumulative values, because the standards consider the maximum permitted quantities per km (on the test bench or in real driving) under different conditions and operating cycles. The absolute measurement (by mass) of substances in the case of gases requires accumulation volumes and detection or separation systems whose cost is very high, so they are practically inaccessible to repair shops.

On the other hand, the diesel exhaust gas analysers that are available and affordable for workshops are proportional measurement tools that work by determining the relative composition of a flow of gas under continuous and sufficient stabilized flow conditions.

The gas analysers that are suitable for diesel vehicles must evaluate the following elements:

- CO_2: Product of complete combustion of the dosed fuel, the transformation of the CO in the catalyst to CO_2, and the formation of CO_2 as a result of the decomposition of the AdBlue in NOx SRC systems.
- O_2: A leftover from the combustion that was not involved in the transformation processes of the pollutant substances.
- CO: The product of incomplete combustion of the hydrocarbons which must be transformed into CO_2 in the catalyst.
- HC: Gasified fuel that must be oxidized in the DOC.
- NOx: The result of the combination of the O_2 and the N_2 during combustion or in the DOC. Their production is limited by the EGR or they are transformed into N_2 and CO_2 using LNT or SCR systems.

The 4 initial values can be used to mathematically calculate the dosed air/fuel proportion (λ factor) based on the proportion of gases generated by combustion and based on the unburned hydrocarbons. The formation of H_2O as a product of combustion must also be taken into account. The different chemical compositions of petrol and diesel require different calculations to determine the λ factor for each one of these engines.
Most 5-gas analysers are compatible with both fuels (with prior configuration by the user), but the older 4-gas analysers normally do not have this option. The values indicated by these machines refer to a volumetric % with respect to the instantaneous total of the sample (value 100) or to the specific number of particles over a predefined quantity of the analysed sample (ppm - particles per million), thus establishing the mathematical proportionality of the different substances with respect to a common parameter and between them (total volume or one million particles, respectively).
As a general rule, they indicate, in ppm, the substances whose proportion in the total volume is so low that it would require too many decimals (NOx and HCs) to be significant. 100ppm is the equivalent of 0.01%. The reference to the total of the gas sample as a common denominator allows the comparative analysis between the exhaust gases to determine whether their variation and proportion at different operating speeds does or does not correspond to the dosing and conditions under which the combustion took place.
Like opacimeters, the gas analysers currently available on the market work in combination with a desktop or laptop personal computer, which performs the functions of controlling the measurement apparatus as well as the calculations and display of results.

In addition to reducing the cost of the measurement equipment, this combination makes it possible to develop and run specific tests to verify the exhaust-gas treatment systems. The graphic representation of the composition of the gases and their evolution facilitates the comprehension of the data and the analysis of the results.

For these gas analysers, it is important to carry out the required maintenance and calibration, and to change the filters. This allows the machine to be used with its highest level of precision.

TECHNICAL NOTES

This section covers the most common malfunctions related to the treatment of exhaust gases. Depending on the manufacturer and the different models, the number of faults occurring over the years may vary.

These faults are selected from the online platform: www.einavts.com. This platform has a series of sections that specify: make, model, line, system affected, and subsystem, which can be selected independently depending on the desired search.

CITROËN

C3 (FC_), C4 (LC_)	
Symptom	P20E9 - Reducer additive pressure too high. NOTE: This newsletter only affects those vehicles equipped with EURO 6 anti-pollution systems. When taking a reading of fault codes, other codes that are not mentioned here may be recorded.
Cause	Defect in the AdBlue anti-pollution system after carrying out an action on the circuit.
Solution	Repair procedure: • Read the fault codes recorded in the engine control unit with the diagnostic tool. • Confirm that the cited fault code is recorded in the symptom field of this technical note. • Confirm that the symptom indicated in the symptom field of this note occurs. • Purge the AdBlue circuit. • Delete the fault codes recorded in the engine control unit with the diagnostic tool. Carry out a second reading of the fault codes on the engine control unit (ECU) with the diagnostic tool and confirm that the fault codes mentioned in the symptom field of this technical note are NOT displayed. • For further information, contact your usual technical consultant. Carry out a second reading of the fault codes on the engine control unit (ECU) with the diagnostic tool and confirm that the fault codes mentioned in the symptom field of this technical note are NOT displayed. **NOTE**: If fault codes different from the fault code mentioned in the symptom field of this newsletter are displayed in the diagnosis, they should be handled individually. **IMPORTANT**: It is not necessary to replace any unit or component to repair this fault.

LAND ROVER

RANGE ROVER II (LP) 2.5 TD (25 6T (BMW)), RANGE ROVER II (LP) 4.0 (42 D), DISCOVERY II (LJ, LT) 2.5 Td5 (10 P), DISCOVERY II (LJ, LT) 4.0 V8 (56 D), DEFENDER (LD) 2.5 Td5 4WD (10 P), DEFENDER Station Wagon (LD) 2.5 Td5 4WD (10 P), DEFENDER Pick-up (LD_) 2.5 Td5 4WD (10 P)	
Symptom	Power loss. Engine malfunctioning. The engine performance is deficient. Excessive smoke coming out of the exhaust. Black smoke coming out of the exhaust. False explosions.
Cause	Wear of the internal seal of the exhaust gas recirculation (EGR) valve.
Solution	Repair procedure: • Check the condition and operation of the exhaust gas recirculation (EGR) valve. • Replace the exhaust gas recirculation (EGR) valve with its seals modified.

AUDI

Q5 (8R) 2.0 TDI (CAHA), Q5 (8R) 2.0 TDI (CAHB)	
Symptom	P20EE00 - SCR nitrogen oxide (NOx) catalyst, test bench 1 - Low efficiency. P229F00 - Test bench 1, sensor 2 nitrogen oxide (NOx) - Implausible signal. Failure code reported by the engine control unit. The vehicle displays one or several previous fault codes. Malfunction indicator lamp (MIL) on. Pre-heating system warning light lit. The following symptom is observed in the workshop: “Error in functioning of the AdBlue system” **NOTE**: This newsletter only affects those vehicles that are within a specific production date.
Cause	Poor functioning of the nitrogen oxides (NOx) measurement sensor.
Solution	Repair procedure: • Read the fault codes reported by the engine control unit (ECU) with the diagnostic tool. • Confirm that the cited fault codes are recorded in the symptom field of this technical note. • Replace the sensor to measure the nitrogen oxides. • Delete the fault codes reported by the engine control unit (ECU) with the diagnostic tool. • Take a test drive with the vehicle. Carry out a second reading of the fault codes on the engine control unit (ECU) with the diagnostic tool and confirm that the fault codes mentioned in the symptom field of this technical note are NOT displayed. **WARNING**: During the test drive, the AdBlue system performs a self-test, and when it has finished, the warning lights on the instrument panel turn off.

OPEL

ASTRA H 1.9 CDTI (Z 19 DT), SIGNUM 1.9 CDTI (Z 19 DT), ASTRA Mk V (H) Fastback 1.9 CDTI (Z 19 DT), VECTRA Mk II (C) Ranchera familiar 1.9 CDTI (Z 19 DT), ASTRA Mk V (H) Ranchera familiar 1.9 CDTi (Z 19 DT), ZAFIRA Mk II (B) 1.9 CDTI (Z 19 DT), ASTRAVAN Mk V (H) 1.9 CDTi (Z 19 DT)	
Symptom	P1901 - Incorrect functioning of the line of the particulate filter pressure sensor circuit. Power loss. Vehicle in low power or emergency mode. Malfunction indicator lamp (MIL) on.
Cause	The diesel particulates filter (DPF) is clogged as a consequence of several interrupted DPF regeneration cycles. The type of operation is not in line with the technology installed on the vehicle (multiple short trip cycles or continuous driving in the city).
Solution	Repair procedure: • Carry out a static regeneration of the particulates filter with the diagnostic machine. • Read the fault codes reported by the engine control unit (ECU) with the diagnostic tool. • Delete the fault codes reported by the engine control unit (ECU) with the diagnostic tool. • Re-programme the engine control unit (ECU) with updated software. • Carry out a second fault code reading at the control unit with the diagnostic tool. **NOTE**: Notify the vehicle user of the need to adapt a continuous driving cycle of about 20 minutes at a high RPM; the warning of this need will appear on the instrument control panel by means of a flashing coil resistor.

EureTechFlash aims to demystify new technologies and make them transparent, to stimulate professional repairers to keep pace with technology.

Complementary to this magazine, EureTechBlog provides weekly technical posts on automotive topics, issues and innovations.

Visit and subscribe to EureTechBlog on
www.euretechblog.com

Eure!Car®
CERTIFIED MASTERCLASSES

The technical competence level of the mechanic is vital, and in the future may be decisive for the continued existence of the professional repairer.

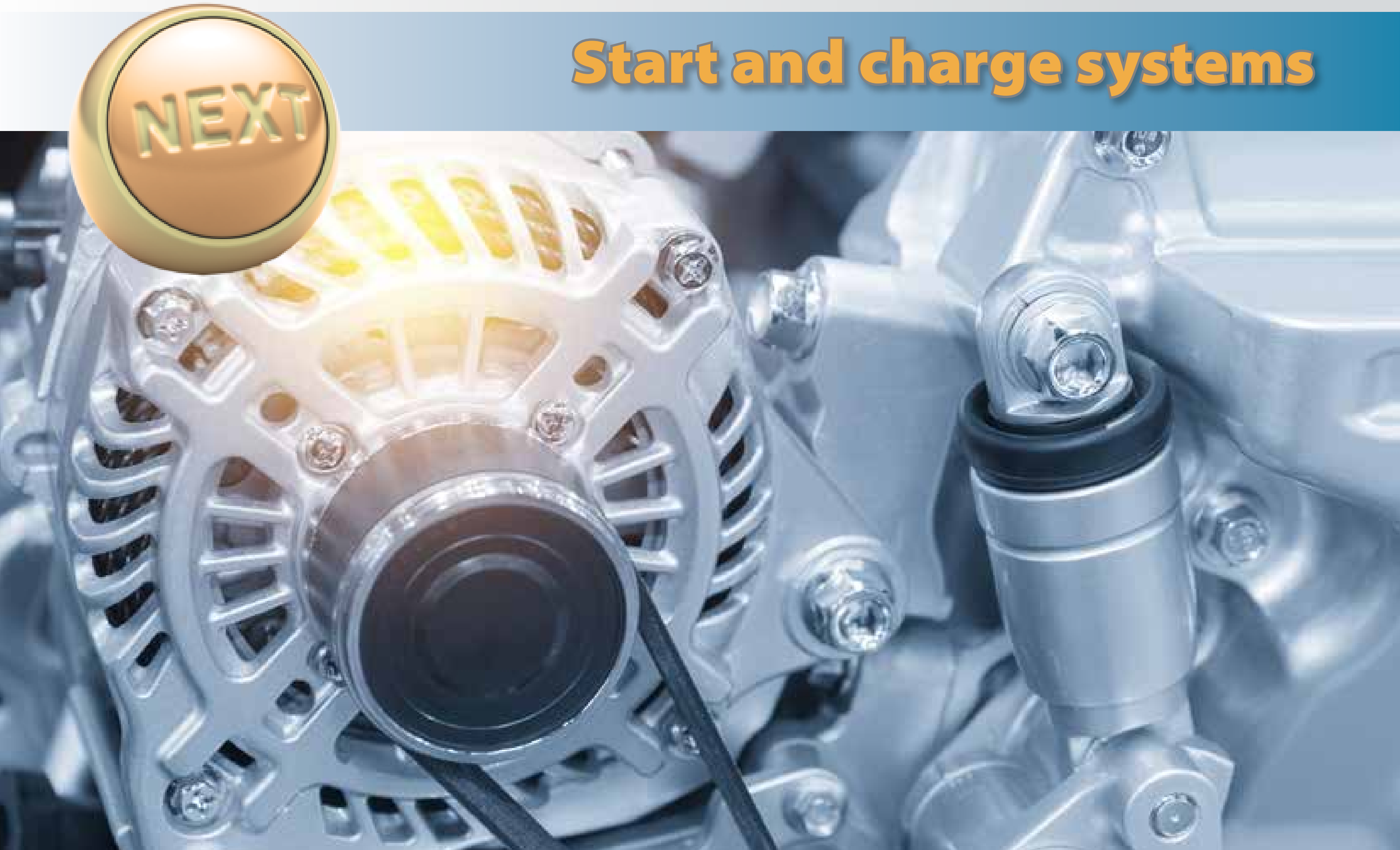
Eure!Car is an initiative by Autodistribution International, with headquarters in Kortenberg, Belgium (www.ad-europe.com). The Eure!Car program contains a comprehensive series of high-profile technical trainings for professional repairers, which are given by the national AD organizations and their parts distributors in 48 countries.

Visit **www.eurecar.org** for more information or to view the training courses.

industrial partners supporting Eure!Car

bilsteingroup, febi, SWAG, BOSCH, brembo, CHAMPION, Continental, DENSO, elring Das Original, EXIDE TECHNOLOGIES, FERODO, Gates, HELLA, KYB Our Precision, Your Advantage, MAHLE, MANN FILTER, metelligroup AUTOMOTIVE PASSION, MONROE, Niterra, Nissens, PHILIPS, SCHAEFFLER, SKF, SNR Brand of NTN corporation, tematic AUTOMATIC TRANSMISSION EXPERTS, TRW, Valeo, VARTA CLARIOS, ZF

Start and charge systems



Disclaimer : the information featured in this guide is not exhaustive and is provided for information purposes only.
Information does not incur the liability of the author.