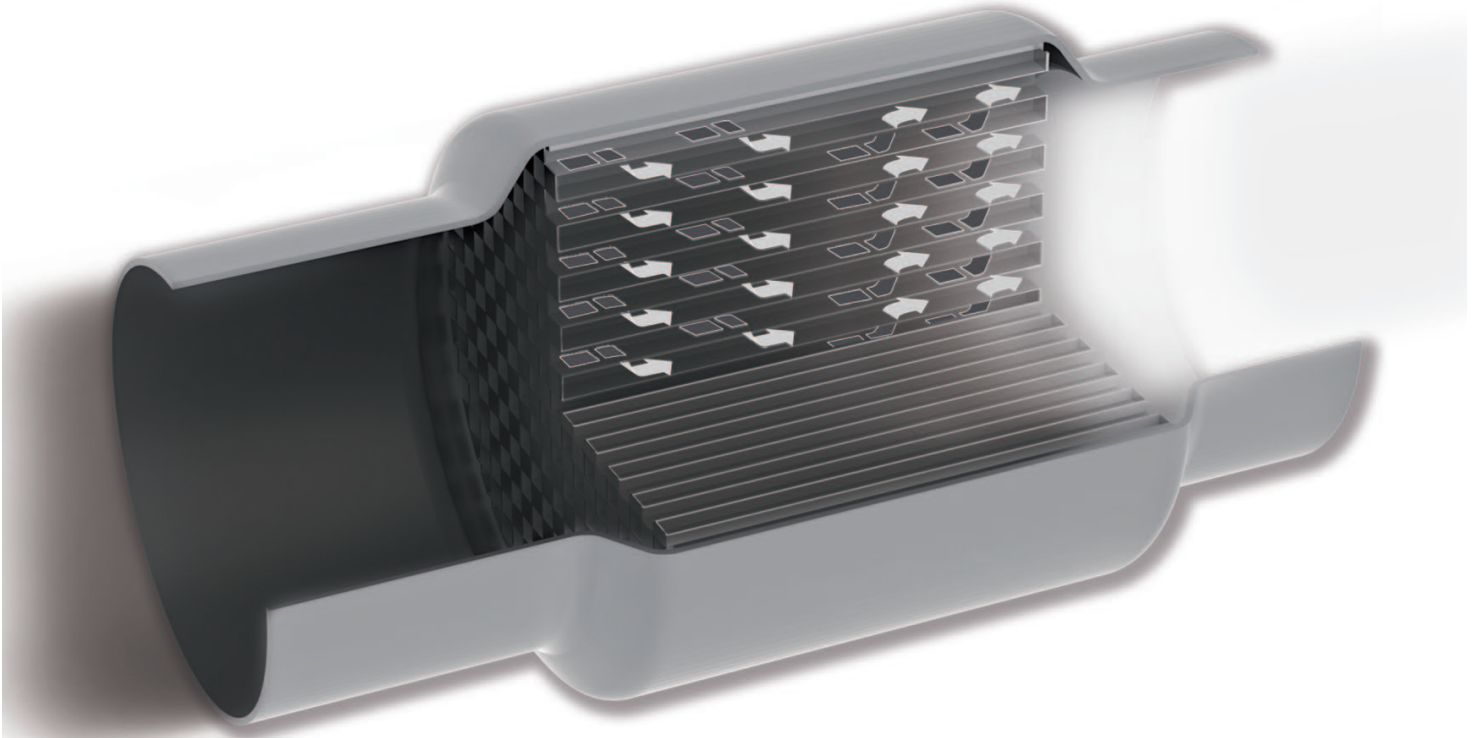


Diesel Particulate Filter: Exhaust aftertreatment for the reduction of soot emissions



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A diesel particulate filter (DPF) can remove virtually all the soot particulates (PM) from the exhaust gas emitted from a diesel engine to ensure compliance with very strict emission standards. Regardless of the actual emission limit, diesel particulate filters satisfy the needs of operators who place importance on achieving extremely low soot emissions.

Diesel particulate filters mean less soot

The emission regulations for diesel engines are becoming increasingly stricter worldwide, which makes modifications to the drive systems necessary. As a basic principle, MTU's approach to achieve compliance is to reduce emission levels by means of internal engine enhancements. Depending on the specific emission limits, it may be possible to do without a diesel particulate filter altogether. However, there is a relationship between the production of soot particulates and nitrogen

oxides when internal engine measures are used – if fewer soot particulates are produced during the combustion process, the quantity of nitrogen oxides increases, and vice versa. In situations where emission requirements are very strict, therefore, adding a diesel particulate filter is necessary, since it removes 90 percent or more of the soot particulates from the exhaust.

For example, very stringent emission limits are due to come into force for diesel locomotives in

Europe as of 2012. The EU Stage IIIB standard lowers the limit for particulate matter emissions from its current level of 0.2 g/kWh by nearly 90 percent to 0.025 g/kWh. To comply with this requirement, MTU is equipping the new Series 4000 engine for rail applications with a particulate filter; nitrogen oxide levels, on the other hand, are reduced from 6.0 g/kWh to 3.5 g/kWh solely by internal engine measures using MTU's patented donor cylinder exhaust gas recirculation system.

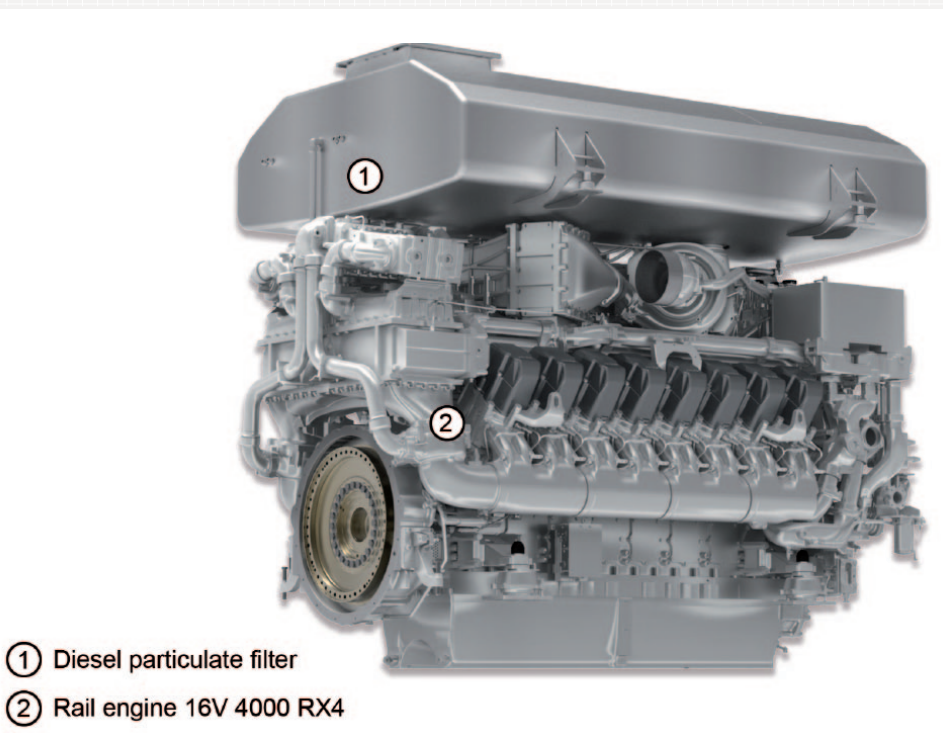
Due to its extremely effective cleaning effect, a particulate filter also satisfies the needs of users who – regardless of the applicable emissions standards – want to achieve the lowest possible soot emissions. Examples of this are private luxury yachts or rail applications, where particulate filters can prevent soot emissions. By using such filters, operators can demonstrate a level of social and environmental responsibility above and beyond their statutory obligations.

Benefits of the MTU particulate filter system

MTU designs the diesel particulate filter for minimal space requirements and long service intervals. This means it can be integrated into the drive system package in a very compact manner (see Figure 1). In existing applications, by optimizing the entire system, consisting of engine and exhaust aftertreatment, the diesel particulate filter can often be installed in the space that is already provided for the exhaust silencer, as the diesel particulate filter also acts as a silencer. This means that customers can

Fig. 1: **Integration of the diesel particulate filter in the engine concept**

MTU designs the diesel particulate filter for minimal space requirements, this means it can be integrated into the drive system package in a very compact manner, demonstrated here by the example of the new Series 4000 rail engine for the EU IIIB emission standard.



easily replace the engine with a new version to conform with new emission standards. MTU drive system equipped with diesel particulate filters, with significantly lower emissions and the same output, exhibit no increase in fuel

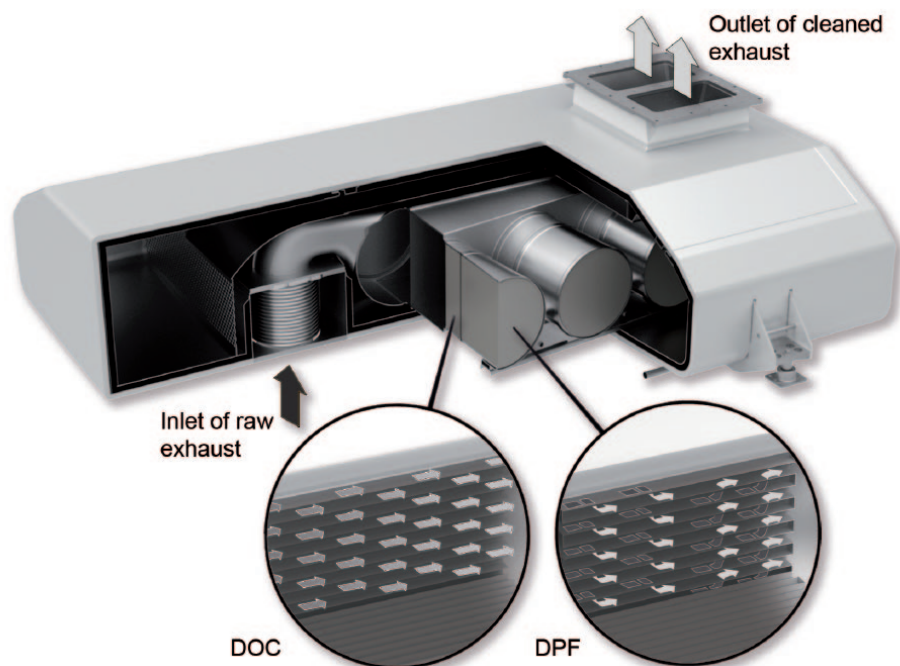
consumption. The servicing intervals of the engine and the filter are synchronized to ensure maximum availability of the application. MTU diesel particulate filters are endurance-tested, series-production solutions that operate reliably across the full span of engine specifications, at extreme altitude as well as at sea level, and both extremely low and high temperatures. This has key benefits – for leasing companies, for instance, who can be flexible in the use of their applications with MTU engines.

Operating principle of the diesel particulate filter

A diesel particulate filter removes soot particles from the exhaust gas that are produced during the combustion process that takes place in the engine (see Figure 2). This is done by directing the exhaust gas through the so-called filter substrate, a fine pore ceramic structure with porous walls inside the filter. Soot particles are deposited on the walls of the channels as the exhaust gas passes through the structure. MTU prefers to use a passively regenerating diesel particulate filter, which uses the CRT effect (Continuous Regeneration Trap) and continuously regenerates itself. With this technology, the exhaust temperatures are sufficient to continuously burn off the soot in the diesel particulate filter under normal operating conditions. Only under extreme climatic conditions or uninterrupted operation under low load is it necessary to support regeneration by adding temperature management.

Fig. 2: **Functional diagram of the particle filtration**

The diesel particulate filter can remove soot particulates from the exhaust gas produced during the combustion process in the engine.



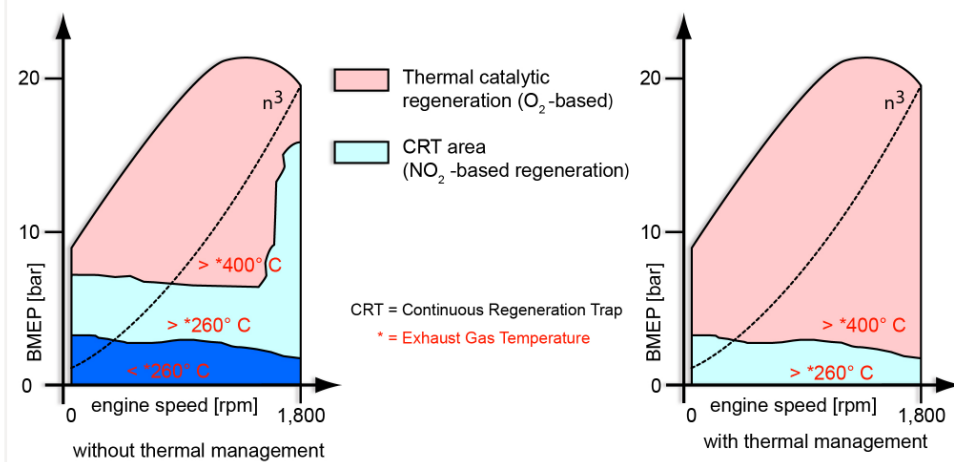


Fig. 3: Diagram of the “passive diesel particulate filter regeneration strategy”

Under normal operating conditions, the engine’s exhaust gas temperatures are high enough to continuously remove soot deposited in the diesel particulate filter. Under extreme conditions, regeneration is supported by thermal management, resulting in a significant increase in the exhaust gas temperature and therefore in soot burn-off.

MTU’s proprietary ECU (Engine Control Unit) engine management system, which was developed in-house, calculates the current soot loading level of the diesel particulate filter with the aid of sensors that detect pressure difference across the diesel particulate filter substrates. If necessary, internal engine temperature management strategies are employed to substantially raise the exhaust temperatures and therefore the rate of soot burn-off temporarily (see Figure 3). Depending on the engine’s operating point at the time, the measures employed may include the reduction of the air-to-fuel ratio, a delayed start of injection for the main fuel injection phase and the inclusion of an optional post injection phase.

For specific areas, such as marine applications, for example, it is not possible to fit a CRT system due to the lower fuel quality. Active regeneration must then be used. The energy required in such cases is provided by a burner in the exhaust gas.

Development at MTU

When developing diesel particulate filters, MTU focuses on the engine and exhaust aftertreatment system as a single unit. All the filter parameters, including filter material, volume and shape, are individually modified to each individual engine and application. Modern simulation methods are used to optimize the exhaust flow through the filter, for example, the accumulation of particles on the ceramic substrate and the filter regenera-

tion. The result is a very compact filter with a high efficiency level and a long service life.

Incorporation in the emission control concept

MTU optimally matches the entire engine emission control concept – internal engine optimization by means of turbocharging, fuel injection and exhaust gas recirculation (EGR) and, if necessary, an SCR catalytic converter (Selective Catalytic Reduction) – to the particulate filter (see Figure 4). Despite the use of a diesel particulate filter, the combustion process is configured for low engine-out particulate emissions to enable a fuel-saving, passively regenerating diesel particulate filter to be used. To ensure that the reactions on which the CRT effect for particulate filter regeneration are based take place continuously in the exhaust system, MTU modifies the engine’s exhaust characteristics accordingly. When designing the engine’s turbocharging system, attention is paid to the need for a high exhaust backpressure capacity with no substantial increase in fuel consumption.

Summary

MTU particulate filters reduce soot emissions by 90 percent and more. This also ensures compliance even with the very strict emission limits specified for diesel engines. To this end, MTU modifies the entire engine emission control concept to the diesel particulate filter, which also includes optimizing the interaction of the other key technologies like turbocharging, fuel injection, engine management and, where applicable, the SCR catalytic converter with the diesel particulate filter. For this reason, compared with versions with no exhaust aftertreatment system, the engines do not consume more fuel and have an equally high power output, with significantly lower emissions. A diesel particulate filter is also the right solution for operators who – regardless of the applicable emission standard – wish to eliminate soot emissions resulting from their applications.

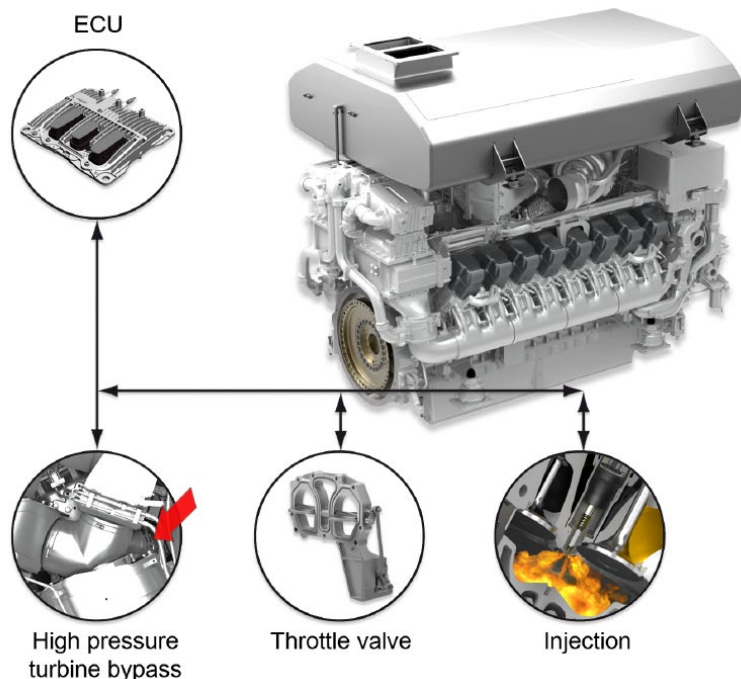


Fig. 4: Adaption of the entire engine emission control concept to the diesel particulate filter

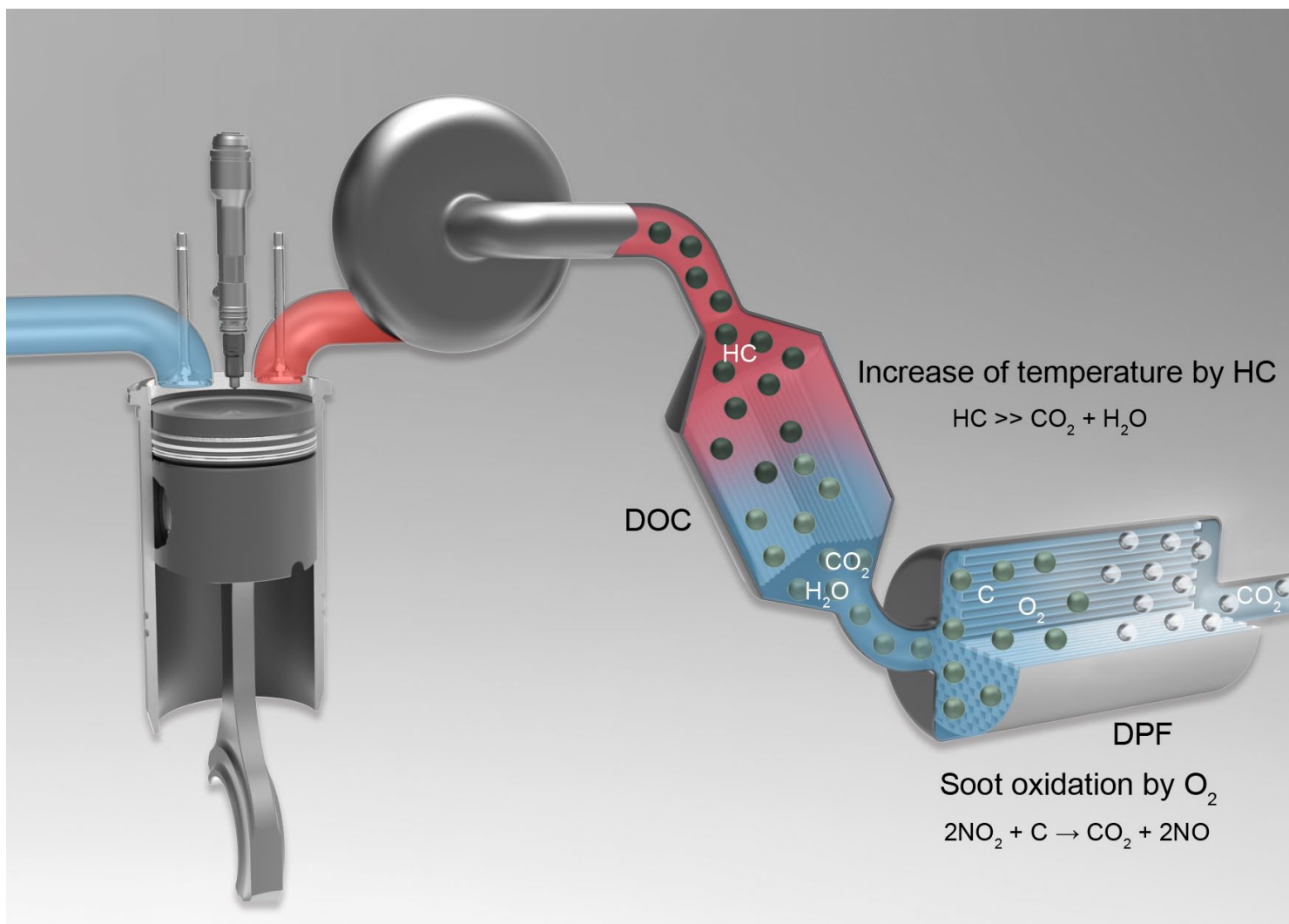
For the best possible performance, the interaction of the other key technologies of turbocharging, fuel injection, engine management and, where applicable, the SCR catalytic converter will be optimized with the diesel particulate filter.

Glossary

Active regeneration

If an engine runs under very low load, the exhaust gas temperature can drop to a point where continuous regeneration can no longer be completely guaranteed. In order to prevent the diesel particulate filter being overloaded when operating under such conditions for a long time, additional thermal energy must be introduced for a short time into the exhaust gas. That can be done, for instance, by injecting fuel into the combustion chamber in one or more post injection sequences or injecting fuel directly

into the exhaust system. This fuel is then completely burned in the engine's oxidation catalytic converter. In this process, it releases enough heat to raise the exhaust temperature in the particulate filter to over 550 degrees Celsius. The use of a burner is also possible. As a result, the deposited diesel soot oxidizes with the surplus oxygen present in the exhaust gas. Active regeneration of the particulate filter is used primarily in cars and commercial vehicles with high specific soot emission levels.



C Carbon
CO₂ Carbon Dioxide
H₂O Water
HC Hydrocarbon
O₂ Oxygen

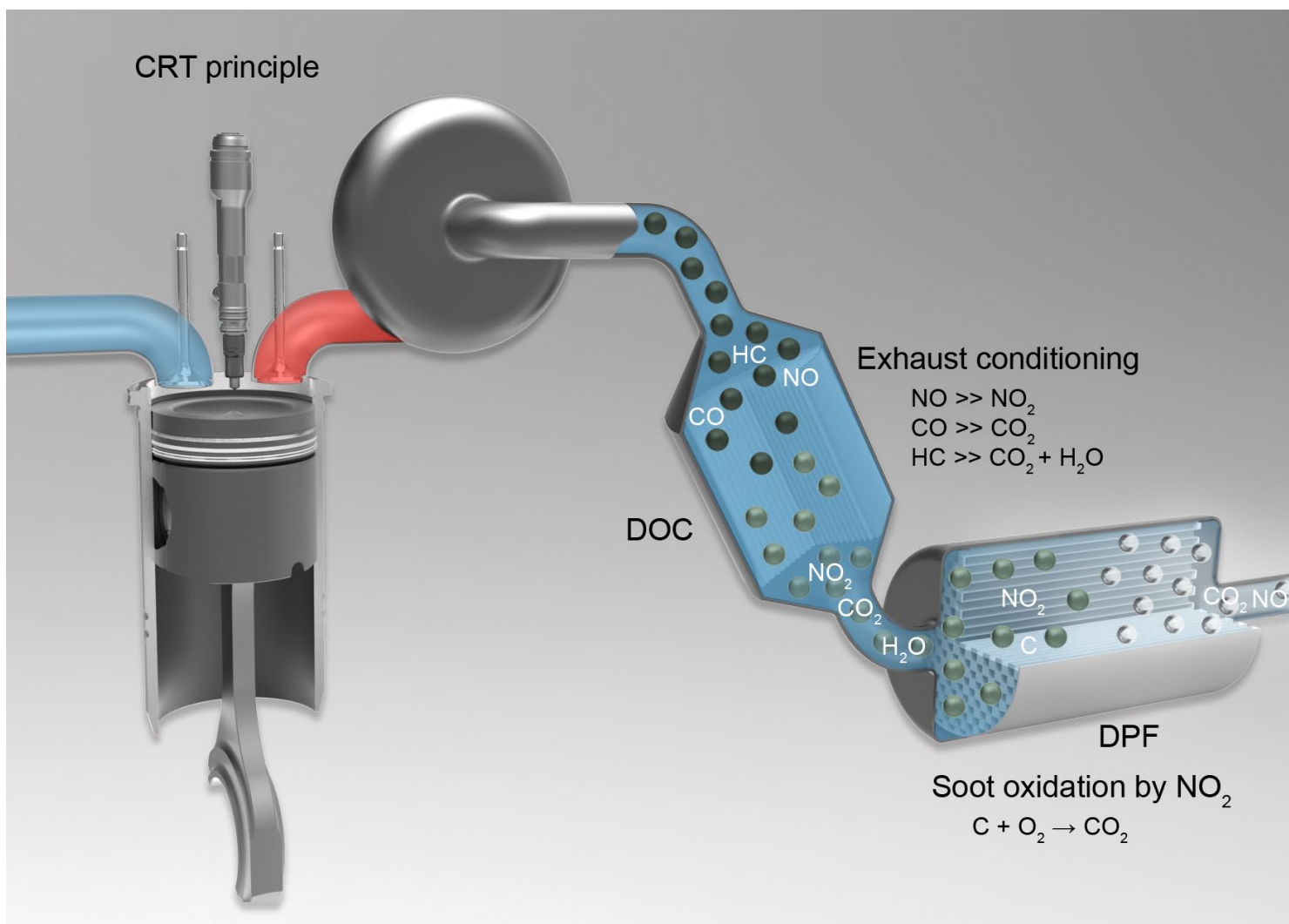
DOC Diesel Oxidation Catalyst
DPF Diesel Particulate Filter

Glossary

Passive regeneration/CRT effect (Continuous Regeneration Trap)

MTU uses the CRT effect for regenerating the diesel particulate filter. This is based on chemical reactions that take place in the engine's exhaust aftertreatment system. First of all, nitrogen dioxide (NO_2) is produced in the oxidation catalyst from the nitrogen monoxide (NO) in the exhaust gas. In the diesel particulate filter, the process is reversed and

the soot deposited in the diesel particulate filter is continuously burned off. Hence the name "Continuous Regeneration Trap" (CRT), i.e. a continuously regenerating filter. This effect is also referred to as passive regeneration. In contrast to active regeneration, the reaction requires no additional energy.



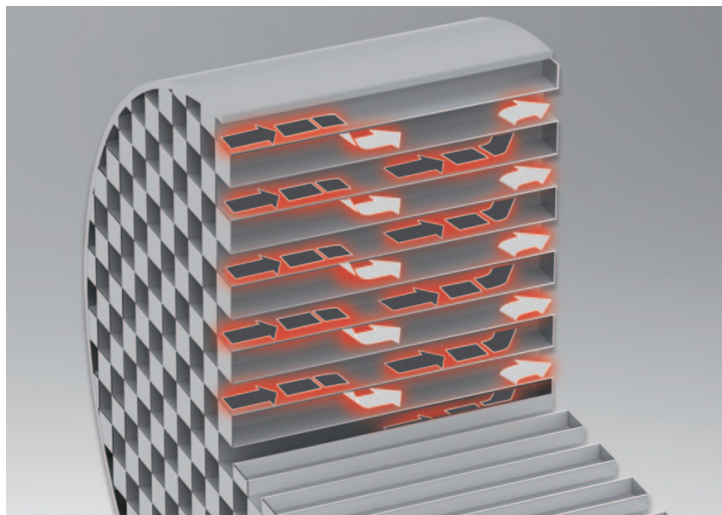
C	Carbon
CO	Carbon Monoxide
CO₂	Carbon Dioxide
H₂O	Water
HC	Hydrocarbon
NO	Nitrogen Monoxide
NO₂	Nitrogen Dioxide

DOC	Diesel Oxidation Catalyst
DPF	Diesel Particulate Filter

Glossary

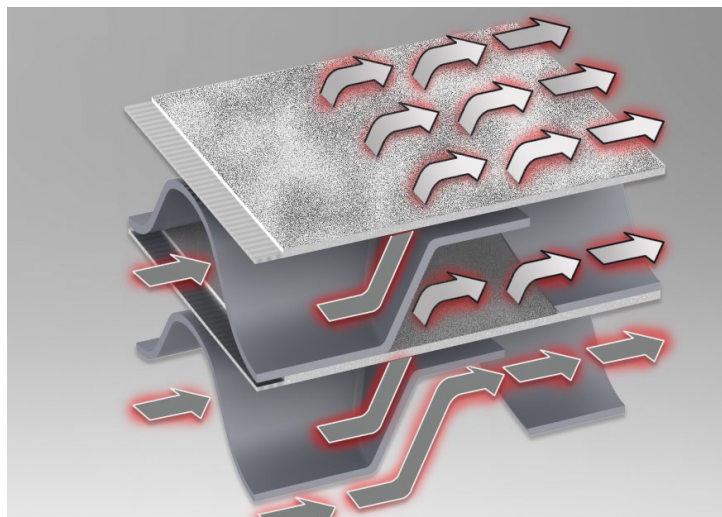
Wall-flow diesel particulate filter

In the case of a wall-flow diesel particulate filter, the entire exhaust flow is passed through the fine porous ceramic walls of the filter element. This makes very high particle filtration rates of over 90 percent possible. However, filter regeneration must be possible in a wide range of engine applications, to prevent clogging. The resulting high exhaust backpressure would lead to higher fuel consumption and, in the worst case, to filter and engine damage. Consequently, including the engine's thermal management measures is of particular importance in the development of the system. Wall-flow particulate filter systems can be combined both with passive and active regeneration. MTU uses a wall-flow diesel particulate filter in the new Series 4000 engine for rail applications for example.



Partial-flow diesel particulate filter

A partial-flow diesel particulate filter, strictly speaking, is a particle separator. The separation effect is based on a sharp deflection of the exhaust gas flow that results in some of the particles to be separated. Compared with a wall-flow diesel particulate filter, it produces similar and in some cases higher exhaust backpressures. A partial-flow diesel particulate filter cannot clog up. However, the filtration rate with an exhaust pressure comparable to that of a wall-flow diesel particulate filter is only 30 to 40 percent.



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