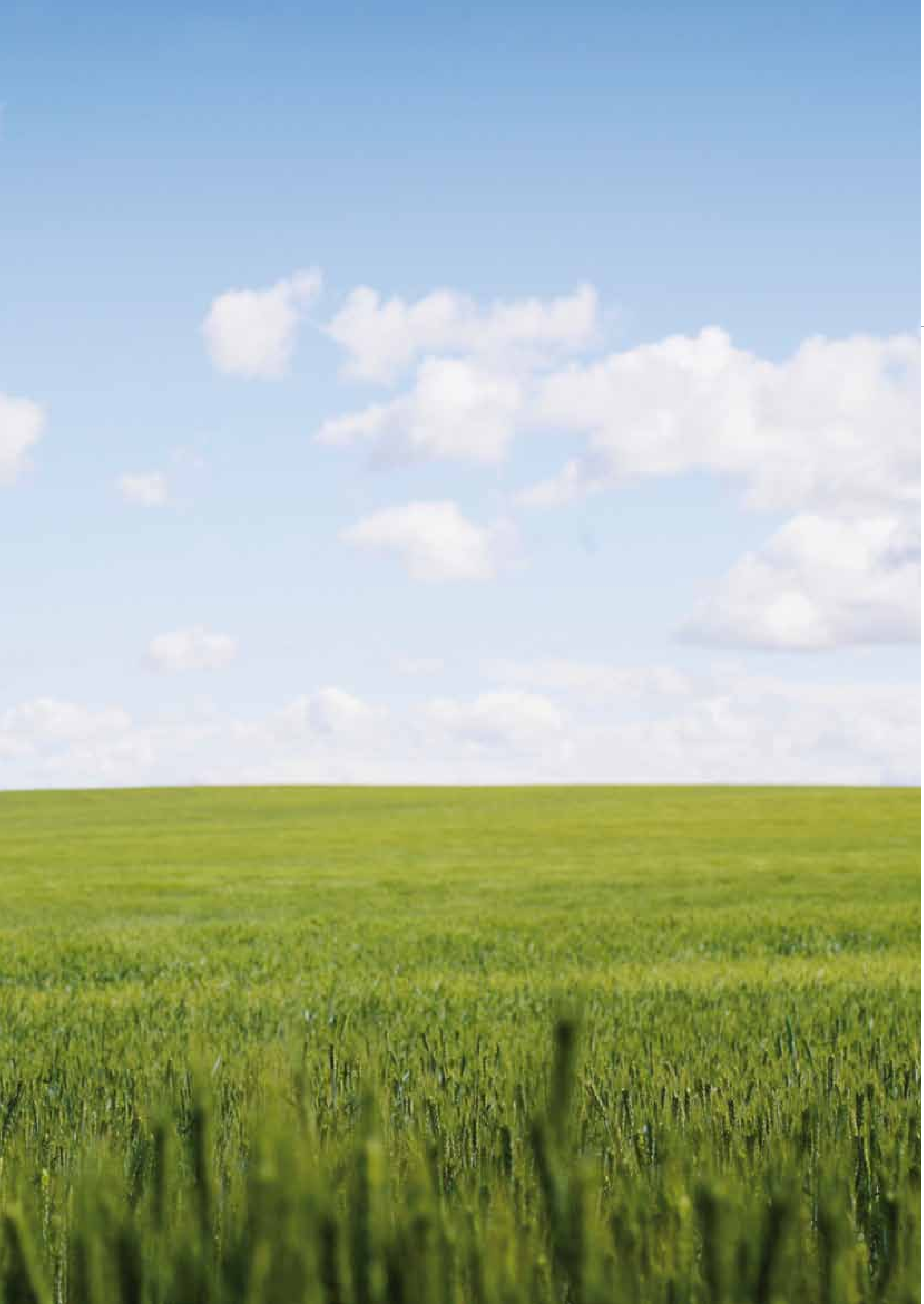
Power Technology

For a greener planet

Engineering the Future – since 1758.

MAN Diesel & Turbo



Engineering the Future – since 1758.

MAN Diesel & Turbo is one of the world's leading suppliers of diesel and gas engine power plants, both land-based and floating. Over the last century, we have built thousands of diesel power plants worldwide. The experience we have gained and the technology we have developed over that time enables our specialists to tailor power plants to the individual needs of customers all over the world.

During this long history, the companies within the MAN Group have always been world leaders in their fields, both in design engineering and the commercial application of new technologies. More recently, we have pioneered the innovative integration of mechanical engineering with state-of-the-art electronics.

More than ever before, MAN Diesel & Turbo is focusing on the environmental performance of our engines. Using our unrivalled grasp of large engine technology, we aim to make our engines progressively cleaner, more powerful and more efficient.

With our firm commitment to reducing emissions while increasing fuel efficiency and power density, and with our active partnership with environmental institutions and development banks, we intend to be part of the global emissions solution.

Environmentally Friendly and Efficient

Meeting emission regulations

Throughout its history, the diesel engine has always been considered the most efficient system for converting fuel into mechanical energy – a situation expected to continue into the foreseeable future.

In recent years, local and global regulations covering exhaust gas emissions from engines have become increasingly stringent. In relation to large power plants, these regulations focus on limiting emissions of nitrogen oxides (NO_x), sulphur oxides (SO_x) and particle emissions.

By optimising the combustion process, the engine designer can reduce the formation of NO_x and, to some extent, the formation of particle emissions. However, ash content in the fuel plays a large role in determining the amount of particle emissions, and the fuel's sulphur content is solely responsible for the production of SO_x emissions.

Most recently, emissions of the greenhouse gas carbon dioxide (CO_2) have also come under scrutiny. In this respect, the reciprocating internal combustion delivers clear benefits: due to its high efficiency, it produces much lower CO_2 emissions than other prime mover technologies.

National and regional emission regulations

Most countries' environmental laws include emission regulations. Of course, these laws take precedence over any other guidelines. These national environmental laws vary widely, reflecting the diversity of the countries themselves.

In the near future, european countries will adopt new EU directives, replacing their own emission regulations.

Whatever the applicable emission guideline or legislation, MAN Diesel & Turbo has the power plant technology to ensure compliance.

Maximum Emission Reduction

World Bank emission guidelines

In 2007 and 2008, the World Bank's commercial finance arm, the International Finance Corporation (IFC), published new environmental, health and safety guidelines. These guidelines are applicable in all cases where financing is based on World Bank conditions, such as financing by development banks, or where financing is supported by export credit agencies. Many countries have also adopted the World Bank guidelines into their local emission regulations.

The World Bank guidelines categorise power plants based on the fuel used – gas, liquid or biofuels. Within each category, emission levels are set according to the power plant's size. The larger the power plant, the more stringent the emission limits. For more details, please refer to the World Bank guideline emission levels in the table on this page.

It should be noted that the World Bank emission guidelines are guidelines only and do not have the power of law. In other words, they are a flexible instrument: emission limits may be adjusted higher or lower for a specific project, if justified by an environmental assessment study.

	Small Power Plants 3 MWth to ≤ 50 MWth (Fuel Input)			Medium Power Plants > 50 MWth to < 300 MWth (Fuel Input)					
All values referenced to 15% O_2	PM mg/Nm3	S in fuel % (SO2) (mg/Nm3)	NOx mg/Nm3	PM mg/Nm3		S in fuel % (SO2) (mg/Nm3)		NOx mg/Nm3	
Air shed class.				NDA	DA	NDA	DA	NDA	DA
Natural gas	n/a	n/a	200 (spark ignited) 400 (dual-fuel) 1600 (compression ign.)	n/a	n/a	n/a	n/a	200 (spark ign.) 400 (dual-fuel)	
Liquid fuels	50-100 a)	1.5-3.0 (870-1750) b)	1460-1600 (bore<400) c) 1850 (bore≥400)	50	30	2 (1170)	0.5 (290)	1400 (bore<400) 1850 (bore>400) 2000 (DF)	400

Biofuels all power plant sizes	PM mg/Nm3		S in fuel % (SO2) (mg/Nm3)		NOx mg/Nm3	
Air shed class.	NDA	DA	NDA	DA	NDA	DA
Biofuels Gas fuels other than nat. gas	50	30	n/a	n/a	30% higher than those for nat. gas or liquids	400

	Large Power Plants ≥ 300 MWth (Fuel Input)					
All values referenced to 15% O_2	PM mg/Nm3		S in fuel % (SO_2) (mg/Nm³)		NO_x mg/Nm3	
Air shed class.	NDA	DA	NDA	DA	NDA	DA
Natural gas	n/a	n/a	n/a	n/a	200 (spark ign.) 400 (dual-fuel)	
Liquid fuels	50	30	1 (580)	0.2 (116)	740 d)	400

Foot notes:

a) *Up to 100 mg/Nm³ is permitted if justified by project specific consideration (e.g. economic feasibility of using low ash fuel or adding ESP to meet 50mg/Nm³, and available environmental capacity at site).*

b) *Up to 3% S is permitted if justified by project specific considerations (e.g. economic feasibility of using low S fuel or adding FGD and available environmental capacity at site).*

c) *For bore diameter < 400mm up to 1600 mg/Nm³ is permitted if justified to maintain energy efficiency.*

d) *For all bore diameters, contingent upon water availability*

Data for information only

Air shed classification:

NDA: non-degraded air shed

Means: no or few pollution existing at site

DA: degraded air shed

Means: significant pollution already existing at site

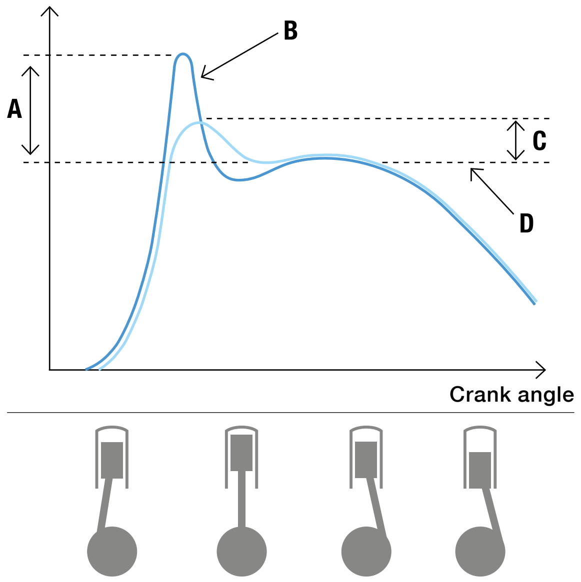
NO_x Countermeasures
Optimised combustion

Optimised combustion

Nitrogen oxides, or NO_x are formed when the nitrogen in the air reacts with the oxygen in the air during the combustion process, at a high temperature and under extreme pressure.

Accordingly, the primary goal of modern engine design is to reduce NO_x formation by optimising the combustion process. This can be achieved by avoiding high temperature peaks and generally making the combustion process smoother.

These "primary measures" – meaning features of the engine itself – can reduce emissions without requiring additional materials, making them attractive. However, the challenge is to implement these measures without compromising on efficiency.



A Temperature increase inside the cylinder non optimized combustion

B NO_x generating peak

C Temperature increase inside the cylinder optimized combustion

D NO_x forms exponentionally over this temperature

NO_x formation as a function of combustion temperature

Secondary measures

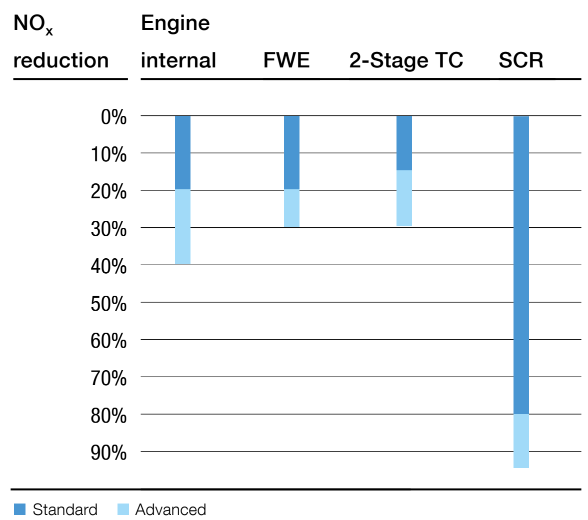
Secondary measures, on the other hand, comprise systems for conditioning the fuel and combustion air to eliminate combustion temperature peaks, or to remove NO_x from the exhaust gas itself by after-treatment devices.

All secondary measures developed by MAN Diesel & Turbo can be added to a basic power plant configuration in a modular way to meet tighter emission regulations. MAN Diesel & Turbo offers a range of secondary measures, including fuel-water emulsion (FWE), humidification of combustion air and selective catalyst reduction (SCR).

Tailored solutions

MAN Diesel & Turbo has the expertise to provide customers with the ideal combination of primary and secondary measures. The result: the best possible emissions reduction solution to suit any specific engine application.

Depending on the power plant application and technical and economic viability, the latest primary NO_x reduction measures from MAN Diesel & Turbo may be available for retrofit on engines already in the field.



Effectiveness of MAN Diesel & Turbo state-of-the-art NO_x reduction measures

NO_x Countermeasures

Optimised combustion

Combustion chamber geometry

Optimising the mix of fuel and air in the cylinder achieves more complete, homogenous combustion, avoiding temperature peaks (“hot spots”) which cause over 90% of NO_x formation.

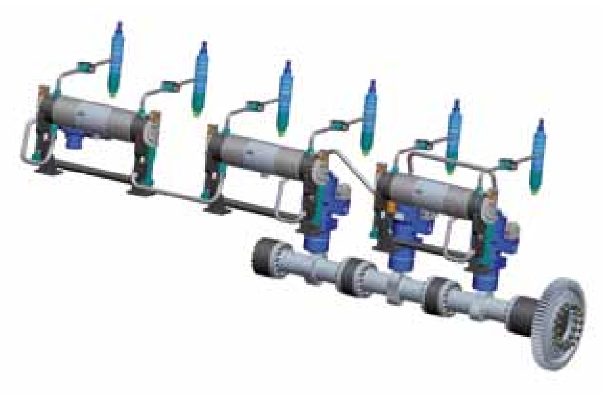
The new low-swirl cylinder heads and high compression re-entrant pistons designed by MAN Diesel & Turbo improve gas flow, decreasing NO_x formation.

The combustion temperature – and as a result, the NO_x formation – may also be decreased by retarded injection. However, this measure increases the specific fuel consumption – what is known as the “diesel dilemma”.

Advanced injection control by common rail

The common rail fuel injection system developed by MAN Diesel & Turbo allows extremely precise and flexible control of injection pressure, timing and duration across the entire engine load range.

While conventional injection systems are designed to function best at a particular point of operations, i.e. full load operation, the common rail injection system allows optimal engine performance, emissions and fuel consumption across a wide spectrum of part loads.

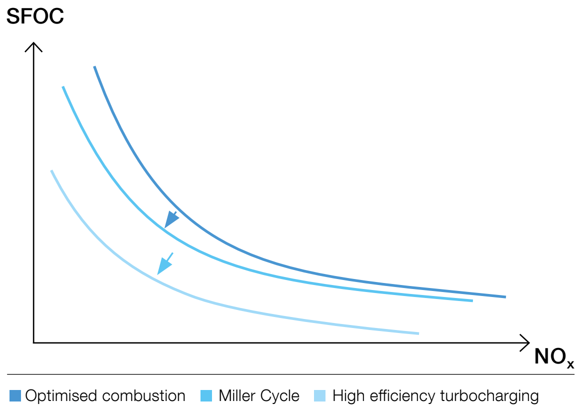


The MAN Diesel & Turbo common rail fuel injection system

Miller Cycle / Variable valve timing

The Miller Cycle is a technique involving the early closure of the inlet valves before the piston reaches its lowest centre position. This causes the intake air to expand and cool after the inlet valve has closed. As a result, combustion temperature peaks at a lower level, reducing NO_x formation.

However, MAN Diesel & Turbo’s variable valve timing (VVT) technology and highly efficient turbochargers, with their increased pressure ratios and variable turbine area (VTA), overcome this drawback, maintaining clean combustion over an extremely wide operation range.

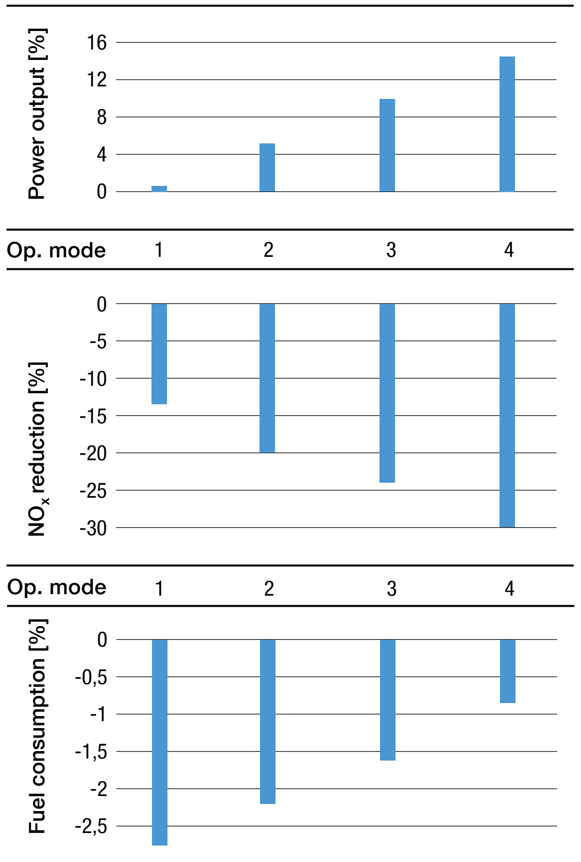


Effects of MAN Diesel & Turbo’s advanced primary NO_x reduction measures

NO_x Countermeasures

Two-stage turbocharging

Effects of Two-Stage Turbocharging



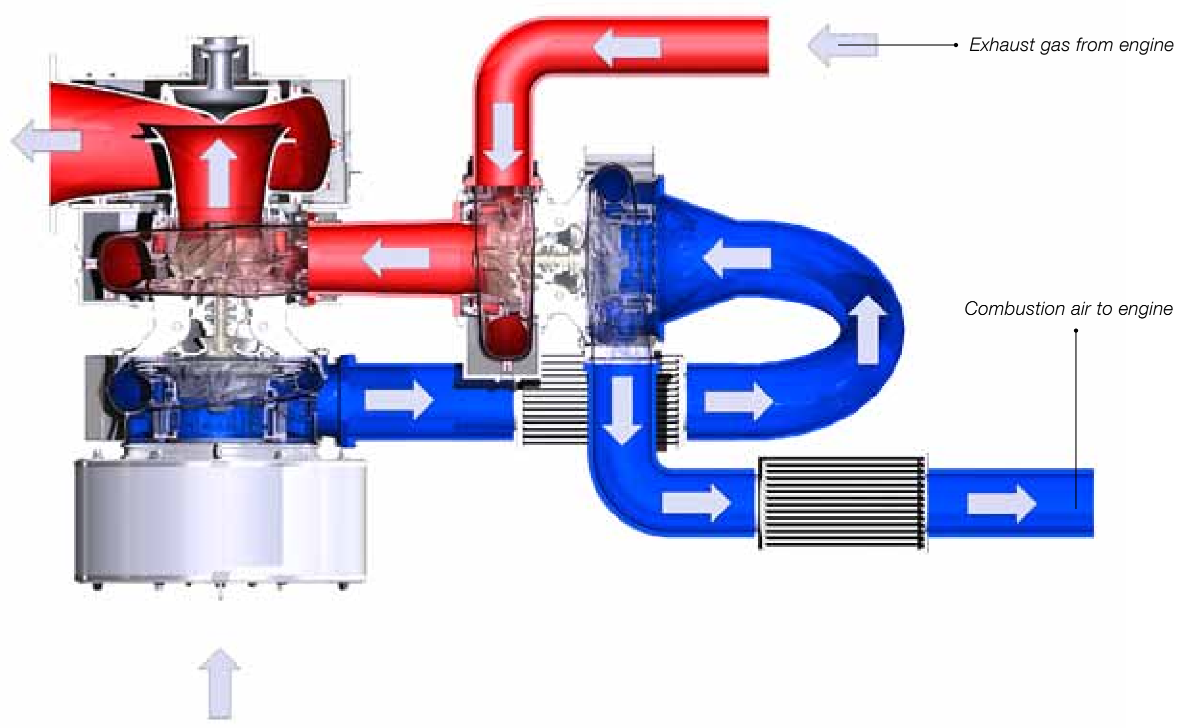
Two-stage turbocharging

Two-stage turbocharging, also known as called sequential turbocharging (STC) consists of two turbochargers operating in sequence. This allows very high combustion air pressure ratios, opening up a whole new dimension of operational possibilities.

The excess combustion air can be used for enhanced Miller Cycling with significant fuel savings – and further reducing NO_x emissions.

Alternatively, the excess of combustion air can be leveraged to significantly increase the engine power output. Although this does not save as much fuel, it does allow a greater reduction of NO_x emissions within a wide operation range.

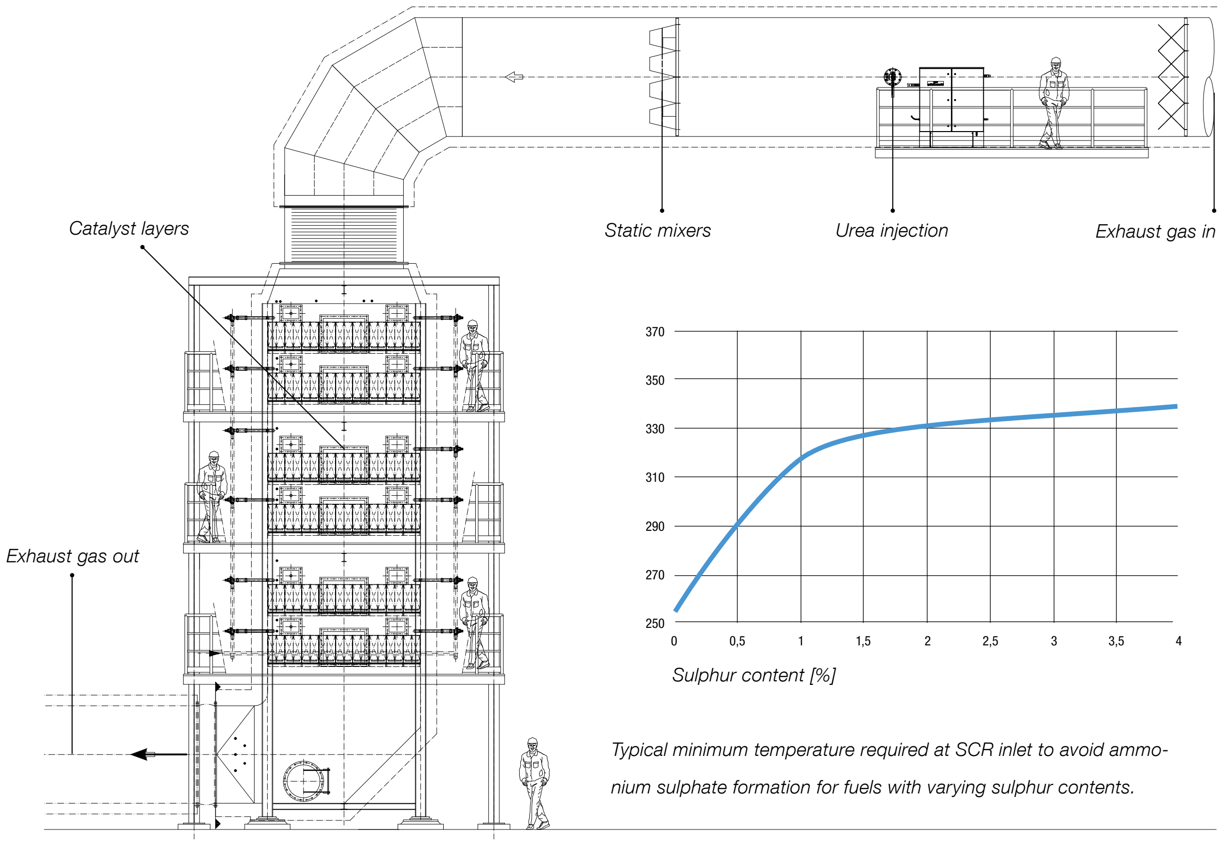
Two-stage turbocharging is a modular system located upstream from the engine, designed in a way that enables most MAN Diesel & Turbo power plants to be retrofitted.



Two-stage turbocharging principle

NO_x Countermeasures

Wet solutions & after-treatment



Typical minimum temperature required at SCR inlet to avoid ammonium sulphate formation for fuels with varying sulphur contents.

As with primary measures, wet technologies aim to eliminate the temperature peaks responsible for the majority of NO_x formation. MAN Diesel & Turbo offers two wet technologies, fuel-water emulsification (FWE) and combustion air humidification.

Fuel-water emulsification (FWE)

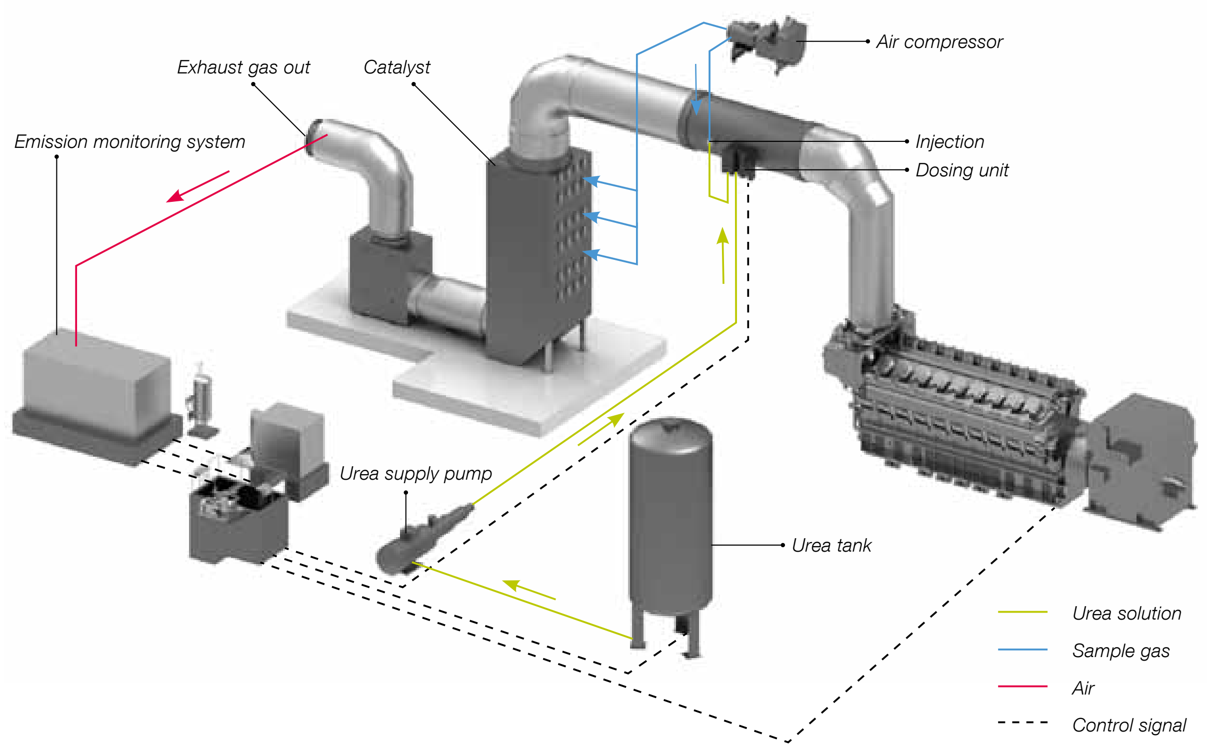
In the fuel-water emulsification process, water is mixed with fuel and emulsified in a special FWE module upstream from the engine. The emulsion can be made of up to 30% of water and 70% liquid fuel.

The emulsion is then injected into the combustion chamber. During the combustion process, the water evaporates, reducing the combustion temperature, and as a result, NO_x formation. Evaporating water atomises fuel very effectively, making the combustion process even more homogenous.

Humidification of combustion air

NO_x formation during combustion also depends significantly on humidity in the combustion air. The lower the humidity, the higher the NO_x level in the exhaust gas, and vice versa.

Accordingly, in the event of low ambient air humidity, water can be sprayed onto the combustion air upstream from the turbocharger. This can be done until the saturation limit has been reached.



Catalytic after-treatment

Catalytic after-treatment entails inducing chemical reactions in the exhaust gas to break down harmful substances like NO_x into harmless components such as nitrogen and water. This can only be achieved with a catalytic reactor.

Selective catalytic reduction (SCR) of NO_x

Selective catalytic reduction involves injecting a reducing agent – such as ammonia or urea – into the exhaust gas flow upstream from a catalytic reactor. Hydrous urea solution, which is easier to handle, is more suitable for this process than ammonia.

In the exhaust gas stream, urea decomposes into ammonia and CO_2. The ammonia reacts with NO_x on the surfaces of the catalytic reactor and reduces NO_x to nitrogen and water. The system is capable of reducing the NO_x levels in exhaust gases by around 80% – in advanced systems with larger reactors and high urea consumption even up to 95%.

Selective catalytic reduction is sensitive to SO_2 in the exhaust gas, which reacts with the ammonia to form ammonia sulphate. This forms deposits which can clog the catalyst and greatly reduce its effectiveness. Depending on exhaust gas temperatures, reliable SCR operation requires fuel with low sulphur content.

If a SCR is used to reduce NO_x in the exhaust gas, the engine can be operated at full load with maximum efficiency: no NO_x reduction measures are required in the engine itself. This advantage offsets the additional effort involved in operating a SCR system.

SO_x Countermeasures

Sulphur in, sulphur out

SO_x emissions are solely the result of the sulphur content in the fuel – they cannot be influenced by the engine. Any sulphur burned will be emitted as SO_2 or SO_3 in the exhaust gas. This means that SO_x emissions can only be reduced by secondary measures, i.e. fuel conditioning or exhaust gas after-treatment.

Low sulphur fuels

Low sulphur fuels are the most obvious way to prevent SO_x emissions. But low sulphur fuel is not always available, and removing sulphur from the fuel often can be costly.

No-sulphur fuel: natural gas and biofuels

In 2006, MAN Diesel & Turbo introduced its latest dual-fuel engine, the 51/60DF. This can run on either gaseous fuel ignited by 1% distillate fuel micro-pilot injection or on 100% liquid fuel (distillate or heavy fuel oil).

MAN Diesel & Turbo's dual-fuel technology features seamless switchover between gaseous and liquid fuels at any load.

A cost-effective and efficient derivate from the 51/60DF engine is the 51/60G gas engine, running on gas only. Its outstanding efficiency and clean emissions make this engine ideal for co-generation power plants, even in dense urban areas.

Because the 51/60DF and the 51/60G engines are derivates from the popular 48/60 diesel engine, these technologies can be easily retrofitted on the 48/60 heavy fuel oil engine for any application. Many MAN Diesel & Turbo engines also can be operated on biofuels, which do not contain sulphur.

Exhaust gas scrubbing

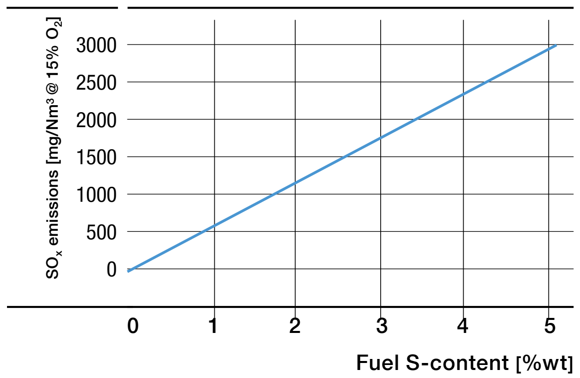
If low sulphur fuel or natural gas is not available, SO_x has to be removed from the exhaust gas by scrubbing with alkaline material. In diesel power plants, three different methods of scrubbing are generally used:

- Wet scrubbing with diluted milk of lime
- Semi-dry scrubbing with limestone slurry and spray absorbers
- Dry scrubbing with hydrated lime

Which of these three scrubbing methods is deployed depends mainly on the amount and quality of water available. Another factor is the white smoke plume caused by wet scrubbing, which may not be acceptable in environmentally-sensitive or urban areas. Moreover, semi-dry and dry scrubbing with a fabric filter system can only can be used if exhaust gas is cooled down by a boiler to a maximum of 200°C.

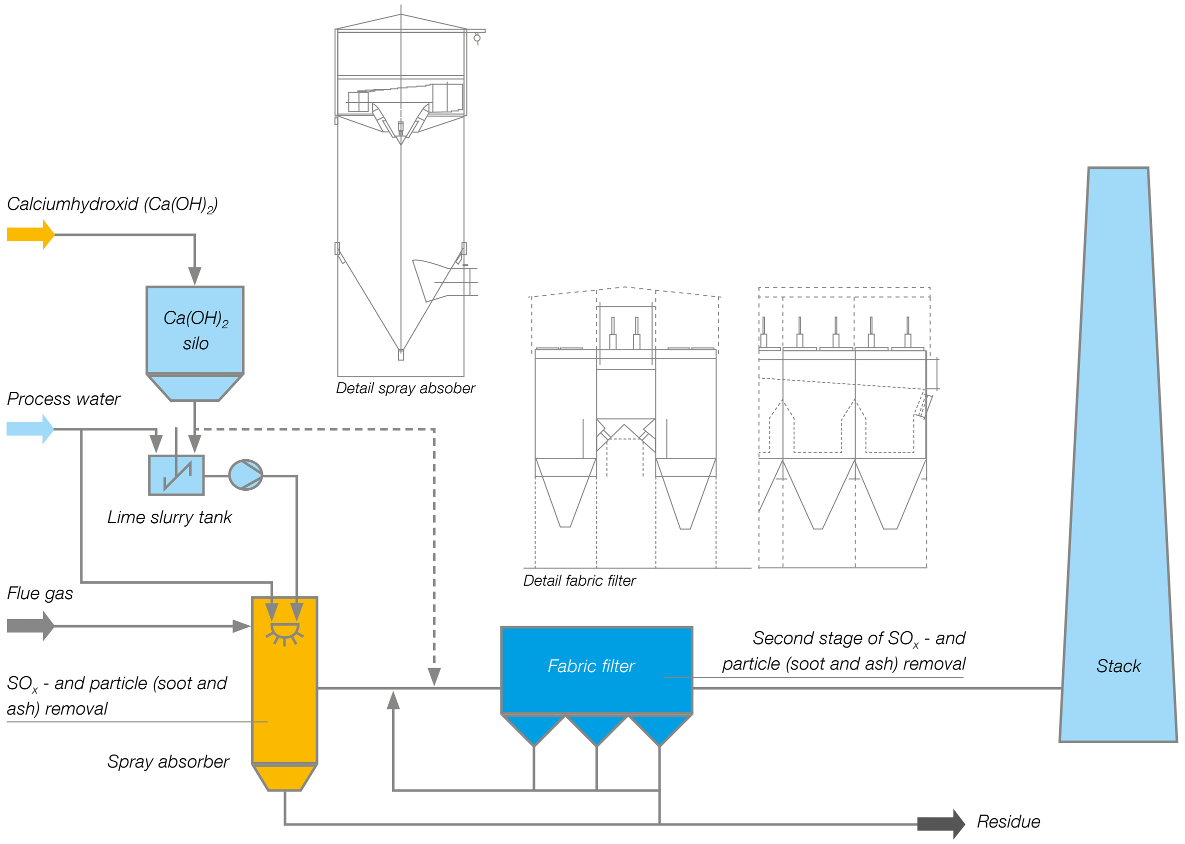
The three methods have different investment costs and operational costs. For example, wet scrubbing involves higher investment, but lower operational costs than dry scrubbing.

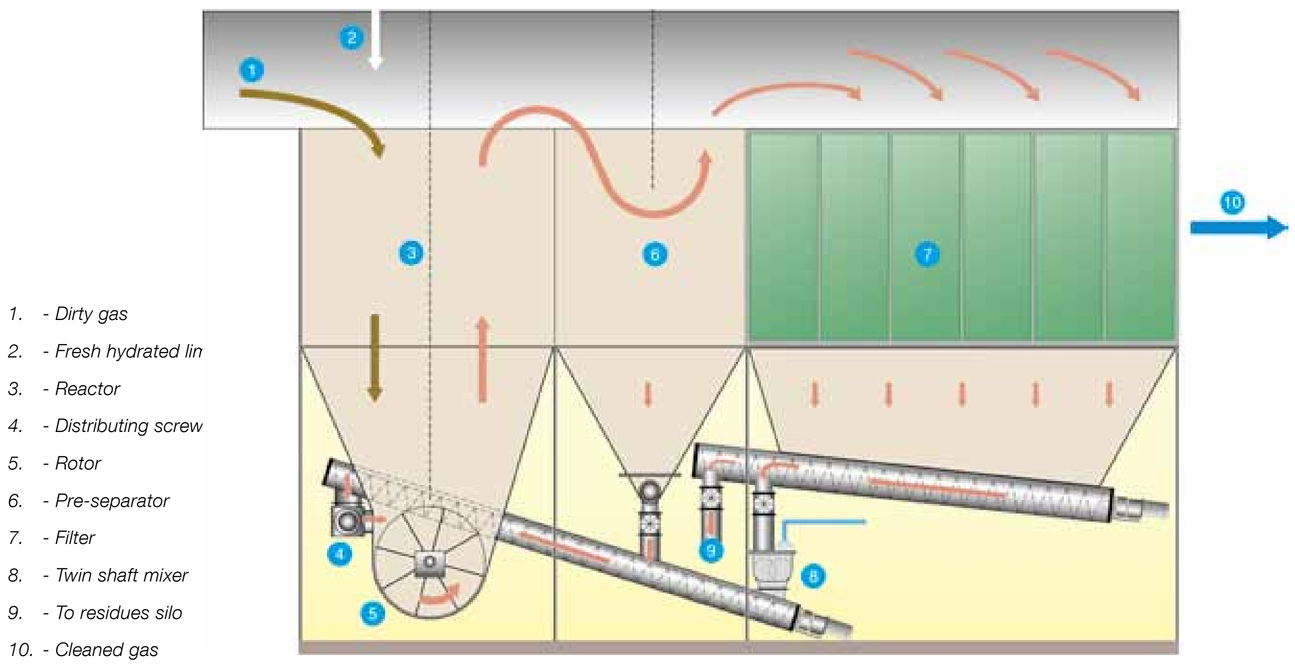
SO_x Emissions vs. Fuel S-Content



SO_x Countermeasures

Semi-dry and dry scrubbing methods





Semi-dry SO_x scrubber with spray absorber

Semi-dry scrubbing with spray absorber

Semi-dry SO_x scrubbing with a spray absorber is a compromise between wet and dry scrubbing. Accordingly, investment and operational costs are in between these methods.

Limestone, preferably calcium hydroxide, is mixed with water to form lime slurry which is pumped into a spray absorber. In the spray absorber, the lime slurry is atomised by a rotating sprayer and blown into the exhaust gas stream. The humidity of the lime slurry is adjusted so that the water evaporates without causing a plume of white smoke at the stack.

The atomised lime slurry reacts in the spray absorber with sulphur dioxide to create water and gypsum, which is partially removed in the form of residue from the bottom of the spray absorber. Some of the remaining gypsum and non-reacted limestone is taken with the exhaust gas stream and filtered out by a fabric filter system.

The fabric filter system also filters out particle emissions from the engine. This means that no extra particle filter is necessary for these particles.

Semi-dry spray absorption can remove approximately 80% of the SO_x from the exhaust gas.

Dry scrubbing

In dry scrubbing, hydrated lime is blown into the exhaust gas stream inside a reactor chamber. In this chamber, the sulphur dioxide in the exhaust gas starts to react with the lime, forming gypsum. A rotor blows the exhaust gas and lime mixture into a second reactor chamber where the sulphur dioxide-lime reaction continues.

In the next chamber, any partly-reacted lime and gypsum is pre-separated from the exhaust gas and conveyed back to the rotor to be blown into the exhaust gas flow again.

After the pre-separator, the exhaust gas is ducted to a fabric filter system where the rest of the gypsum and non-reacted lime powder is completely filtered out. The filtered material, gypsum and non-reacted lime, is partly conveyed to a re-conditioner (twin shaft mixer) for re-use, while the remainder is deposited in a residue silo.

The fabric filter system also filters out particle emissions from the engine. This means that no extra particle filter is necessary for these particles.

Dry spray scrubbing can remove approximately 80% of the SO_x from the exhaust gas.

Particle Countermeasures

Clean combustion & particle filtering

Total solid particles (TSP)

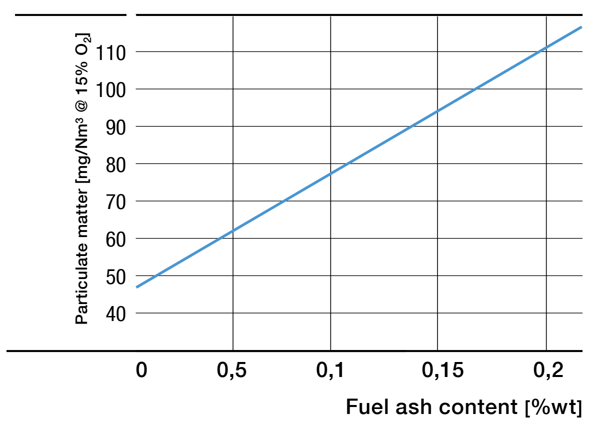
Total solid particles (TSP) or particle matters (PM), as the particle emissions are named in all relevant emissions regulations, mainly consist of soot and ash. Soot is produced when fuel is not burned completely, while ash is made up of solid particles resulting from ash content already in the fuel and ash from lube oil burned during the combustion process.

Clean combustion

The most obvious method to reduce soot is to ensure complete and clean combustion in the cylinder.

To achieve this, fuel injection, turbocharging and combustion chamber geometry have to be perfectly matched. The fuel must be atomised and dispersed throughout the combustion chamber so as to be burned with exactly the right amount of air. The combustion chamber has to be as smooth as possible, without any edges where areas of incomplete combustion can arise.

Particle Emissions Influencing Factors



Ash content in fuel

Some fuels, especially heavy fuel oils, naturally contain a small amount of ash. This ash cannot be burned by the engine and will be emitted in the exhaust gas as a part of the particle emissions. This must be taken into account when purchasing fuel, if certain emission levels need to be met.

Particle filtering, electrostatic precipitator (ESP)

If fuel ash content is too high or if the emission demands are stringent, particles must be filtered out of the exhaust gas. This can be done by bag filters or by an electrostatic precipitator (ESP).

Bag filters in the exhaust gas system only can be used if the exhaust gas temperature does not exceed 200°C – in other words, only where exhaust gas heat is used by boilers.

Where the exhaust gas temperature is higher than 200°C, an electrostatic precipitator is the right measure to reduce particle emissions. Here the exhaust gas flow speed is reduced to a minimum in a large chamber. In this chamber, the gas flows along electrostatically loaded plates. The exhaust gas particles are attracted to the negatively loaded plates and attach to the plates. The plates are rapped with a hammer at regular intervals, causing the particles to drop into a silo.

Picture: © Hokolo 3D

Engine Emissions and their Effects

NO_x

NO_x is the collective term for the two oxides of nitrogen:

- Nitric oxide (NO)
- Nitrogen dioxide (NO_2)

Nitrogen (N_2) makes up some 80% of air and is virtually inert at normal temperatures and pressures. However, it will react with the oxygen (O_2) in the intake air of combustion engines, at the temperatures and pressures prevailing in the combustion chamber.

NO_x is instrumental in the formation of low-level ozone, acid rain, and the deposition of nitrates, which act as fertilisers, disturbing the natural ecological balance by over-fertilising the land and sea. Acid rain is the result of NO_x combining with water in the atmosphere to form nitric and nitrous acids. It is considered extremely harmful to both animal and plant life. In particular, it is held responsible for damage to forests and other vegetation.

SO_x

SO_x is the collective term for oxides of sulphur. During combustion, the sulphur (S) present in diesel fuels is oxidised to form sulphur dioxide (SO_2) and sulphur trioxide (SO_3). As with NO_x, the oxides combine with water in the atmosphere to form sulphurous and sulphuric acids, which are major constituents of acid rain. As well as its role in the formation of acid rain, both SO_2 and SO_3 in diesel engine exhaust gases combine with ammonia in selective catalytic reduction systems. The resulting ammonium sulphate forms deposits on the catalyst cores (SCR) and greatly impairs their effectiveness in reducing NO_x.

CO_2

During combustion in diesel and gas engines, the overwhelming majority of the carbon (C) constituent of hydrocarbon fuels is oxidised to carbon dioxide (CO_2) while only traces of carbon monoxide (CO) are formed.

Though not poisonous, CO_2 does not support life and can suffocate at high concentrations. More importantly, it is the most common “greenhouse gas”, capable of absorbing infra-red radiation and therefore a major source of global climate change.

While there are currently no mandatory regulations affecting CO_2, these are expected, and are almost certain to include large engines. However, under international agreements such as the Kyoto Protocol and the European Union’s accord on greenhouse gases, many governments are committed to substantial reductions in total emissions of CO_2 and other gases held responsible for global warming (e.g. methane).

On the incentive side, many countries reward the generation of electric power using renewable fuels, and/or operate carbon-trading schemes. In the latter, organisations employing CO_2 neutral technologies acquire credits which are sold to organisations with a positive CO_2 balance.

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