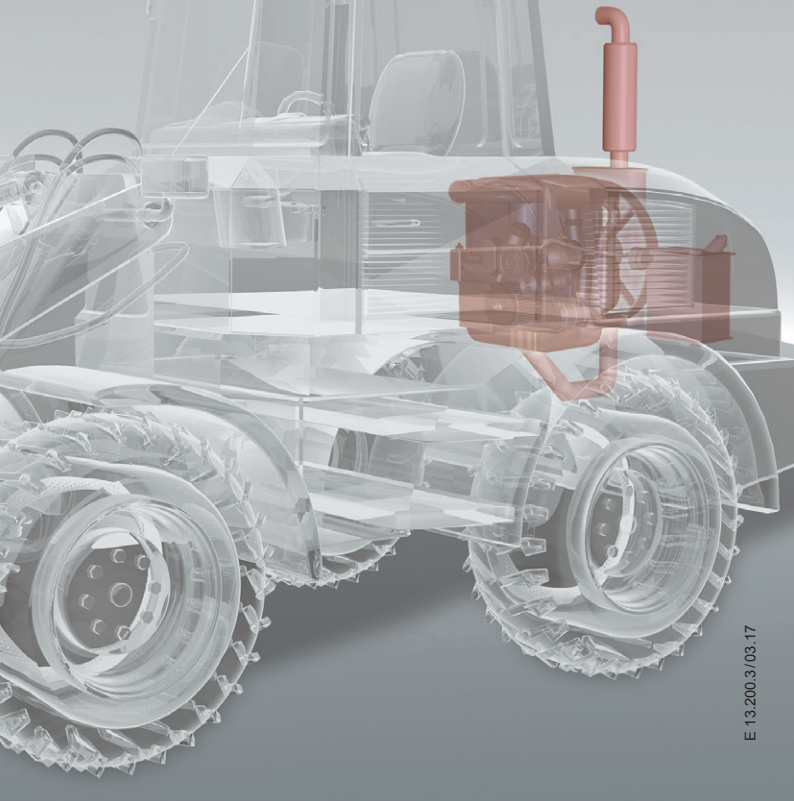
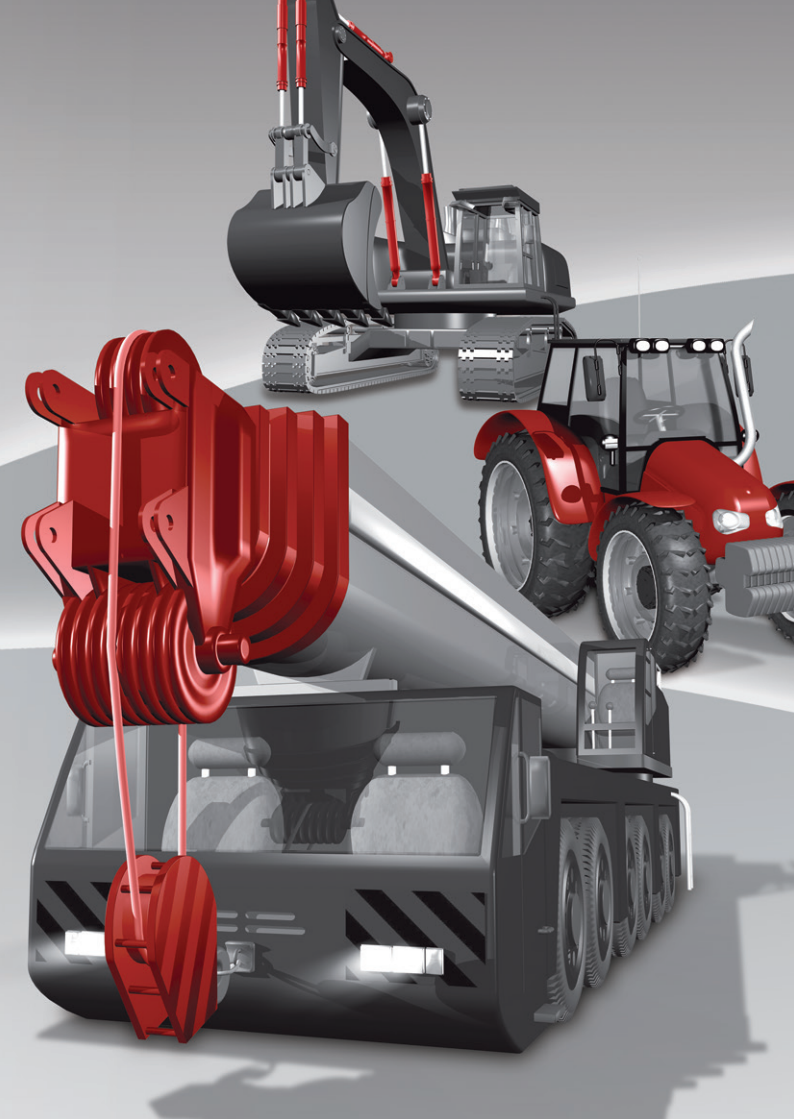
HYDAC INTERNATIONAL

Issue
March 2017

Questions and Answers on the New EU Emission Legislation for Mobile Machines



E 13.200.3/03.17



Questions and Answers on the New EU Emission Legislation for Mobile Machines

With the European Emission Regulation (EU) 2016/1628 – Stage V published on 16 September 2016, the strictest emission limits will in future apply to mobile machines across Europe.
All machines which fall within the scope of **Non-Road Mobile Machinery (NRMM)**, i.e. agricultural, construction and building material machinery, industrial trucks, cranes and even inland waterway vessels, must further reduce their exhaust emissions as of 2019.

The Directive shall apply throughout the EU as of 1 January 2017 and must be implemented as of 1 January 2019. Engines with a power range of 56 kW up to 130 kW are exempt; their effective date is 1 January 2020.

01 *What are the key points of EU Stage V concerning the legislation on reducing emissions further?*

For the first time it concerns engines of all power ranges which are used in the NRMM sector, i.e. from 0 kW up to higher than 560 kW, both spark ignition engines (SI) and compression ignition engines (CI). Moreover, this applies equally to variable-speed and constant-speed engines. The emission limits also apply to gas engines of all power ranges.

In addition to the further reduction of particulate matter (PM), nitrogen oxides (NO_X), hydrocarbons (HC) and carbon monoxide (CO), a particle number (PN) limit of 1×10^{12} #/kWh is also being introduced for engines with a power range from 19 kW up to 560 kW.

02 What is particulate matter (PM)?

Particulate matter or particulates consist mainly of soot (carbon particles) and residues of lubricating oil.

03 What does particle number (PN) limit mean, and what does it mean for the use of engines?

Soot particles result from combustion in engines with an extreme lack of air. Diesel engines and also direct-injection petrol engines are therefore referred to as “lean burn engines” which generate soot particles of different sizes during operation.

EU Stage V introduces a particle number (PN) limit of 1×10^{12} #/kWh for engines with a power range of 19 kW to 560 kW which are used in NRMM. In order to comply with the limit, the additional use of a particle filter will be mandatory.

04 What are nitrogen oxides (NO_x)?

Nitrogen oxides consist of nitrogen monoxide (NO) and nitrogen dioxide (NO_2). Nitrogen oxides are formed when the oxygen and nitrogen in air react under intense heat and high pressure during combustion.

05 What are hydrocarbons (HC)?

Hydrocarbons are a family of compounds composed of carbon and hydrogen, consisting basically of incompletely combusted fuel and oil residues. The concentration of hydrocarbons in diesel exhaust emissions is very low and can be further reduced through the use of high-quality fuels, an efficient combustion process and an exhaust gas treatment system.

06 What is carbon monoxide (CO)?

Carbon monoxide is a compound of carbon and oxygen formed by incomplete combustion in the presence of insufficient air.
Diesel engines operate with a large excess of air and therefore normally only emit small quantities of carbon monoxide.

07 What is carbon dioxide (CO_2)?

Carbon dioxide is one of two natural end products of combustion; the other is water. CO_2 is not toxic and the quantity is directly proportional to the fuel consumption. CO_2 contributes to the so-called greenhouse effect which impacts the climate.

08 *Are CO_2 emissions regulated?*

No, CO_2 is not regulated in the case of mobile machines, but governments, political parties and international and national bodies are placing increasing demands on, for example, the automotive, construction and agricultural industries to supply products with ever-lower CO_2 emissions.
The onus is also on the users of these products to operate the machines in the most fuel-efficient way possible.

09 *How can CO_2 emissions from engines be reduced?*

The only way to reduce CO_2 emissions is to lower the fuel consumption. Fuel-efficient engines and high-efficiency drive and hydraulic systems are therefore also important elements in the pursuit of lower CO_2 emissions.

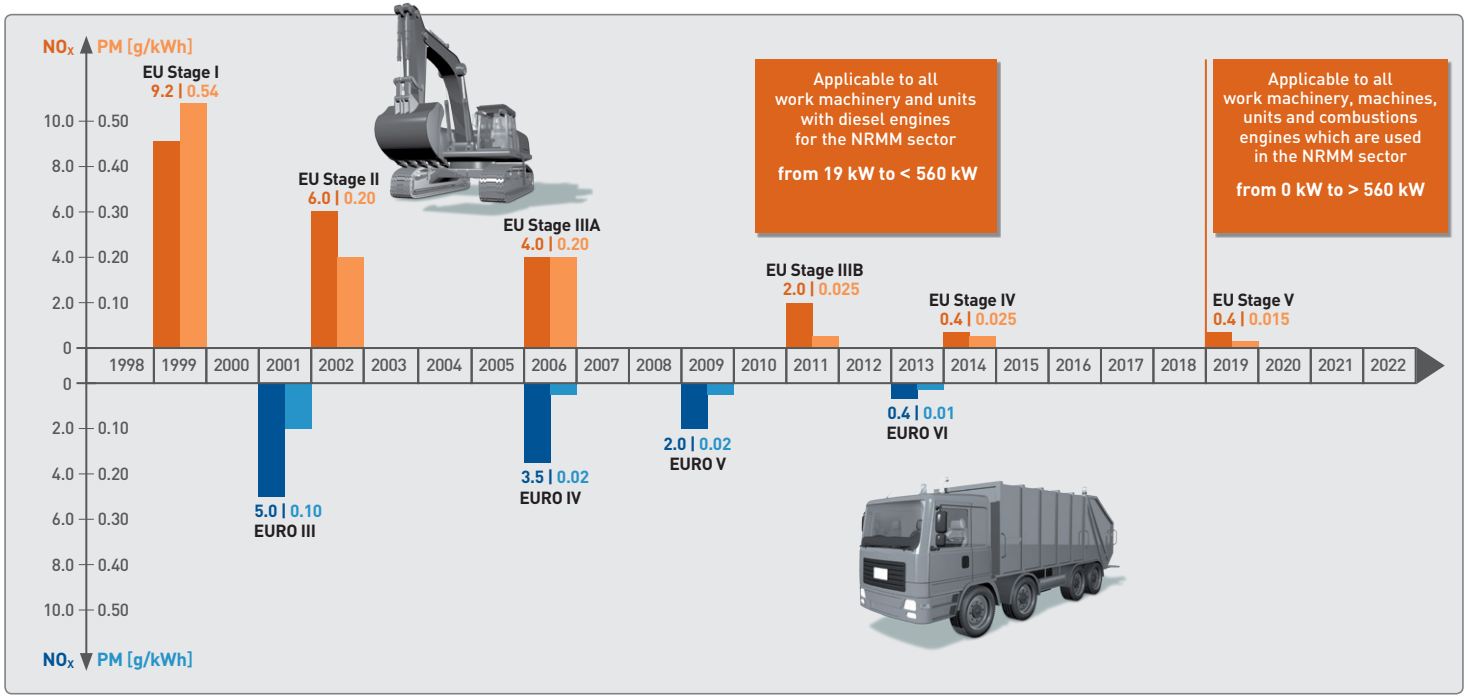
10 *What is the difference in the specified emission levels of EU Stage IV compared to the future EU Stage V?*

For the first time, **all engines** with a power range of **0 kW to higher than 560 kW** for use in NRMM are included in the EU Directive. In order to further reduce the levels of particulate matter (PM), the maximum particle number for engines between 19 kW and 560 kW is limited to 1×10^{12} #/kWh. **All combustion engines** (petrol, diesel, gas, etc.) are included, and it applies equally to both variable-speed and constant-speed engines.

11 *When does Stage V of the European Emission Regulation (EU) 2016/1628 come into effect?*

It was published in the Official Journal of the EU on 16 September 2016, and it is valid without having to be implemented into national law. The emission regulation shall apply as of 1 January 2017 and must be implemented in European production areas as of 1 January 2019.

All engines for Non-Road Mobile Machinery use that are produced on or after 1 January 2019 must comply with EU Stage V, except for engines with a power range of 56 kW to 130 kW; their effective date is 1 January 2020.



12 *Will all new NRMM available for sale in 2019 and beyond, in the market areas concerned, be equipped with EU Stage V-compliant engines?*

Regulation 2016/1628 includes a transitional provision and exception (§ 58) with a transition period of 24 months; during this period it is still possible to put engines of a previous emission stage on the EU market.
The transition period starts with the effective date for placing Stage V engines on the market and essentially applies to all engine categories. They must comply with the previous emission stage and must have been produced by the effective date of Stage V.
The machines with transition engines must have been produced 18 months after the effective date of Stage V at the latest and put on the market no later than 6 months after that.
Engines with a power range of 56 kW ≤ P < 130 kW are exempt. In this case, the effective date for Stage V engines is 1 January 2020, followed by the applicable 24-month transition period.

The following exemptions apply:

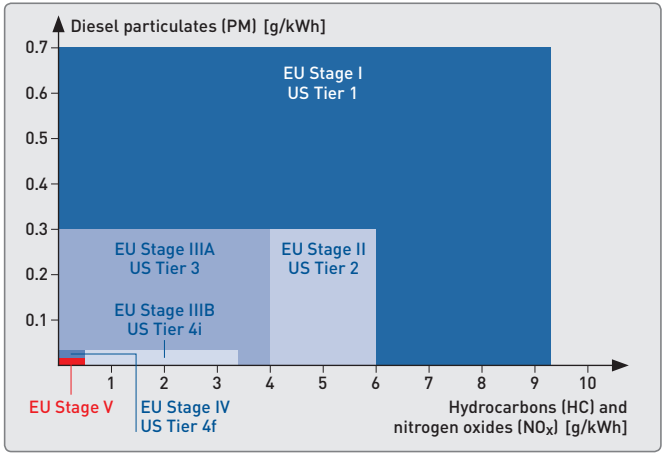
Machine manufacturers with an annual production of less than 100 units and manufacturers of mobile cranes are granted a transition period of 36 months after the effective date of Stage V. The machines / mobile cranes must have been produced 30 months after the effective date at the latest and put on the market within 6 months after that.

13 *Are the regulated EU Stage V and US (EPA) Tier 4 Final emission limits identical?*

Yes, when it comes to the limits for diesel engines they are almost identical, based on the power range in which the engine operates.
However: EU Regulation Stage V has a stricter limit of 0.015 for particulate matter (PM), and it also includes a particle number (PN) limit of 1×10^{12} #/kWh for the engine power range of 19 kW to < 560 kW. The main difference between EU Stage V and US (EPA) Tier 4 Final is that EU Stage V applies to all combustion engines (diesel, petrol, gas) and that Tier 4f in the USA only applies to diesel engines.

14 *Will there be further requirements imposed by governments at a future date regarding the reduction of "non-road" machinery?*

The US (EPA) Tier 4 Final, the strictest emission regulation in the USA, came into force on 1 January 2014. EU Emission Regulation Stage V, a much stricter and more comprehensive regulation, shall apply throughout Europe as of 1 January 2017 and must be implemented as of 1 January 2019.
From today's perspective, it is reasonable to assume that there will not be another, even stricter emission regulation in the near future – neither in the USA nor in the EU.
But rather, other countries or continents will adopt either one or the other regulation.



15 *What technology options are available to meet the demands of the new EU Stage V regarding emission limits?*

NO_X and PM reduction can be achieved in several ways, each having both advantages and disadvantages.
For example, in-engine NO_X reduction always leads to higher PM emission levels, and conversely, in-engine reduction of PM leads to higher NO_X emissions.
Optimisation of fuel injection and air supply, including different EGR (Exhaust Gas Recirculation) configurations (cooled / non-cooled etc.), and various exhaust gas treatment technologies, including soot particulate filters and SCR (Selective Catalytic Reduction) technology are all tools used for NO_X and PM reduction. In order to be able to meet the required particle number (PN) limit, a soot particulate filter must be used.

16 *How does SCR technology work?…*

Selective Catalytic Reduction (SCR) is a technology where a reagent is injected into the exhaust gas flow and mixed in a catalytic converter.
This reduces the NO_x to harmless nitrogen and oxygen. The reagent is a mixture of 32.5 % urea and 67.5 % water and in Europe is commercially known as AdBlue®. Depending on the engine load factor, the consumption of AdBlue® is approx. 4 – 5 % of the diesel fuel usage.

The basic engine must, in any case, be fine-tuned to minimise engine-out PM emissions as required by the EU Stage V emission regulations.

17 *…and DPF technology?*

The Diesel Particulate Filter (DPF) is a device in which the particulates are collected and then oxidised by passive or active regeneration. Advanced electronic control of the process is necessary to ensure effective PM removal in all engine duty cycles of any type.

In addition, the basic engine must be fine-tuned to minimise engine-out NO_x emissions to meet the NO_x levels required by law. Ultra-low sulphur fuels and low-ash lubricating oils are a must for these DPF technologies to function properly.

18 *Will EU Stage V solutions be based on the existing engine platforms or will a new design be required?*

Mobile machines are generally powered by modern high-volume production engines. These engine platforms have been designed from the outset to cope with the higher internal loads arising from the new performance requirements of EU Stage V. Some design changes will, however, be introduced in order to further enhance the performance of the engines.

It is important to mention here that the engine platforms that are normally used for EU Stage V applications are used in road vehicles by prestigious manufacturers and have already undergone more than 2,000,000 km of real-world testing.

19 *Are there any other factors that influence the design of the machines?*

The larger space requirement of the additional systems in the exhaust system means that the existing space must be used very efficiently or new space must be created by reducing other components (e.g. tanks).

Practical Implementation of the Emissions Directive

By the end of 2010: Tier 3 / EU Stage IIIA	Since 2011: Tier 4 Interim / EU Stage IIIB	Since 2014: Tier 4 Final / EU Stage IV	From 2019: EU Stage V
Only diesel engines			All combustion engines
			
- Common rail system - Single-stage turbocharging - External EGR (Exhaust Gas Recirculation)	- Two-stage turbocharging with intercooler - Diesel particulate filter	- Common rail system - Externally cooled EGR - Two-stage turbocharging with intercooler - SCR system AdBlue®	- SCR system with AdBlue® - Use of soot particulate filters - Obligation of the engine manufacturer to monitor the emission limits in the final application (e.g. with PEMS – Portable Emission Measurement System)
Development of costs			
100 %	+40 %	+25 %	+10 %
Installation space required			
100 %	+40 %	+25 %	+0 %

HYDAC's Answers to Energy-Saving, Emissions Reduction and Additional Space Requirements

In its range of products HYDAC holds numerous answers to today's questions on environmental protection, reduction of emissions, and energy and fuel-saving.

Whether cars, commercial vehicles or mobile machinery – the demands made on the most up-to-date components and systems and their future development are practically identical.

HYDAC develops and supplies components and systems:

HYDAC Components...

... for SCR Technology

AdBlue® Filtration

- AdBlue® is an aqueous 32.5 % urea solution which starts freezing at -11 °C
- The filter is used as a suction filter upstream of the pump in the AdBlue® tank
- It is designed as a “lifetime filter” which is also resistant to freezing cycles

AdBlue® Conveyor System on the Basis of a Magnetic Pump

- Self-priming
- Suction height: 3 m
- Anti-freezing
- Integrated heater
- Integrated AdBlue® quality sensor
- Filter (20 µm, contamination retention capacity 100 g)

Technical data:

- Q = 120 l/h
- p = 2.5 bar
- U_{nom} = 24 V
- I = 6.5 A

... for Diesel Filtration

HYDAC Diesel PreCare

- **Diesel filtration and 2-stage water separation**
- **Manual water discharge** (BestCost design) – the conventional, operator-dependent solution
- **Fully automatic discharge** Plug&Play (High-Tech design) – the innovative solution for fully automatic dewatering, independent of the operator, even during suction-side operation
- Suction side pre-filter
- Protects all the pumps and components in the fuel system from water and contamination
- Environmentally friendly due to incinerable filter elements
- Longer service life and increased machine availability

HYDAC Components...

... for Gas Tanks

Oil Separator for Natural Gas Vehicles

CNG (Compressed Natural Gas) may be contaminated with particles and oil during refuelling. Our 2-stage low pressure oil separator removes particles and oil, thus protecting valves and injectors in the CNG system.

Mounting Technology for Gas Tanks

- TÜV certified, patented gas tank mounting clamps with quick release fastenings
- "Multi" swivel bolt band clamp

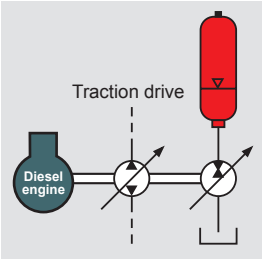
... for Diesel Particulate Filters

Mounting Technology

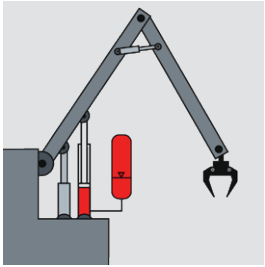
The continued development of the successful "Multi" swivel bolt band clamp made from high-quality stainless steels. Specifically designed for high dynamic loads, thermal stresses, changes in diameter and the effects of strong forces – already successfully applied in series by well-known manufacturers in the mobile industry.

HYDAC Components...

... for Hydraulic Hybrid Technology



Example of a parallel hybrid structure



Example of a load compensation

Product portfolio for hydraulic hybrid technology

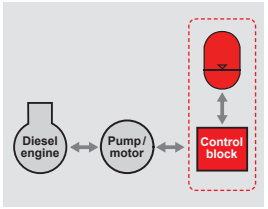
In many mobile machines, the typical work cycles involve phases of high dynamics with pronounced load peaks. This makes it possible to save fuel by implementing hydraulic hybrid systems on the machines.

In all hydraulic hybrid systems, hydraulic accumulators are used to store energy temporarily. Our decades of experience in designing, developing and producing hydraulic accumulators combined with our simulation expertise form the foundation of successful hybrid projects performed in close collaboration with the customer.

With our valve variants, we can create customised control blocks that minimise pressure loss. Tried and tested sensors, safety devices and fastening technology are other typical components for our hybrid systems.
HYDAC's hybrid range is rounded off with innovative hybrid solutions, such as double piston accumulators, that can be used for parallel hybrid concepts and also for load compensation.

- Bladder, piston and diaphragm accumulators and nitrogen bottles (back-up)
- Extensive valve portfolio
- Control blocks / hybrid modules
- Safety devices
- Sensors and control devices (with SIL2 / 3 and / or PLd)
- Mounting technology (various clamps and consoles)

... for Hydraulic Start / Stop Technology



Structure of a hydraulic start / stop system

Example of a "control block + accumulator" solution

In the car industry, electrical start / stop systems are already established technology which allow considerable fuel savings to be made. In mobile machinery, automatically switching off the drive engine when it is idling is also a source of major potential savings, depending on the particular application.

In mobile machinery, existing hydraulic infrastructures can normally be used to realise start / stop functionalities.
For example, work-hydraulics pumps in a modified form can also be used as hydraulic motors. After an automatic "idle stop", the diesel engine is restarted by the working hydraulics pump in motor operation mode. The energy required for this is provided by a hydraulic accumulator that was charged "in the background" during normal machine operation.

The hydraulic start / stop solutions generally provide quicker starting processes than electrical systems, which above all improves operator acceptance.
Since HYDAC has extensive experience in hydraulic control blocks and is a specialist in hydraulic accumulator solutions, we have what it takes to be the perfect development partner for hydraulic start / stop solutions.

HYDAC Components...

... for Cooling Systems

Mobile cooler for excavator applications

Mobile cooler for concrete pump

Combination Cooler CMS

The Emissions Directive is entering its next phase, and the implementation of EU Stage V is just around the corner. It is therefore necessary to recheck whether the cooler must be adapted to the amount of heat to be dissipated from the drive engine. This will influence the size of the cooler and the installation space, which is limited in mobile machinery. It must therefore be used efficiently and intelligently.

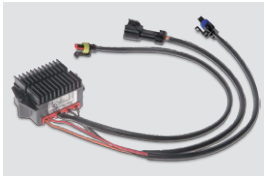
With the mobile CMS cooler range and further optional components, HYDAC offers excellent combination and integration options. Several cooling circuits can thus be covered:

- Charge air cooling (CAC)
- Coolant cooling (RAD)
- Oil circuits: transmission, hydraulics
- Fuel cooling

A variety of equipment can be integrated to achieve a compact design and customised solutions:

- Tank / filter / cooler combinations with integrated fan drive
- Integrated pressure bypass valve (IBP) or thermal pressure bypass valve (IBT)
- Temperature sensors
- Fan control

Combined in one component, they can make a significant contribution to reducing installation space.



Electronic speed control for DC drives with optional reversing function

Mobile cooler with DC drive and ESC for loading crane applications

Fan control block flanged on a hydraulic motor

Fan Drives

The efficiency of a cooler depends largely on the fan control. Various options are used for DC and hydraulic fan drives:

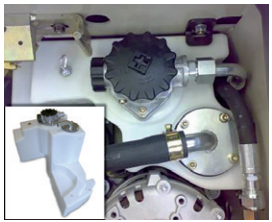
- Electronic speed control ESC
- Hydraulic fan control B-BM-LSTA
- Temperature bypass TB
- Proportional valve for continuous control of the fan speed

This means that the fan speed is tailored directly to the required cooling capacity and just sufficient power is supplied to the fan as is immediately required.

As an option, most controls can also be supplied with a reversing function for the rotation direction, to “purge” the cooler of coarse contamination, e.g. fibrous material, paper or major plant residues).

... for Additional Space Requirements

Tank/filter/cooler combination with hydraulic fan drive for mobile applications



Tank/filter combination in industrial trucks

Tank/Filter/Cooler Combinations

In order to implement the Emissions Directive, additional installation space for the engine is required.
Integrating the filters, cooler and tank in one space-saving and customised unit that is optimised for the installation space allows multiple functions to be combined. Hoses and pipes can be shortened or eliminated. Since the plastic tank also functions as a fan casing, it could be designed to optimise air flow.
All in all, we have a compact, powerful and low-noise module with charge air, oil and coolant cooler, with the oil tank integrated with all functions such as the fluid level gauge, breather filter and return line suction filter.

Advantages:

- Improved use of the existing installation space due to optimised design
- Cost-effective and compact design since integration of filters and coolers eliminates the need for pipework
- Reliable heat regulation and optimum cooling performance despite reduced amounts of cooling water
- Guaranteed system cleanliness
- Easy to service

Plastic Tank Systems

Plastic tanks are primarily used where installation space is limited or in order to reduce weight. This means that complex, customised tank designs are frequently required in addition to our standard designs.

Advantages:

- Improved component cleanliness, since plastic tanks are very clean following production
- Improved use of the existing installation space due to optimised designs
- Inexpensive, since the costs depend on tank volume and not design complexity
- Lower weight
- No risk of corrosion and therefore resistant to aging
- Fewer assembly and test requirements since system is supplied with all add-on components (including air breather and return line filters, oil level gauges, standard fittings, clamping bands, etc.)

Problem:
If inadequately designed, smaller hydraulic tanks can be a cause of air in oil (see following pages).

HYDAC Support: HYDAC offers a wide range of support to avoid air in the hydraulic system (see page 32).

HYDAC Tank Optimisation – Motivation

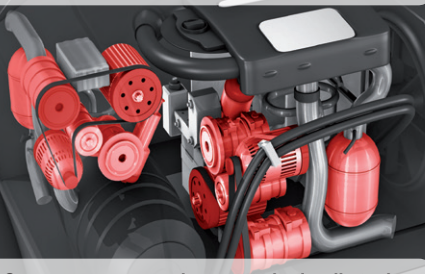
Current requirements for mobile machines:

- Emission Standards
- Energy efficiency
- Power density
- Low life cycle cost
- Noise control
- Vibration protection in the workplace

Changes in the design of both machine and hydraulics

Performance problems

Problems of installation space



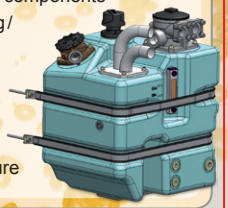
Consequence: e.g. changes to hydraulic tank:

- Tank volume
- Tank geometry
- Dwell time

RISK: Air in the hydraulic system

Effects of air in the hydraulic system

- Efficiency losses in pumps
- Cavitation damage to components
- Accelerated oil ageing / micro-dieseling effect
- Dynamic operating problems / increased compressibility
- Noise generation
- Increase in temperature



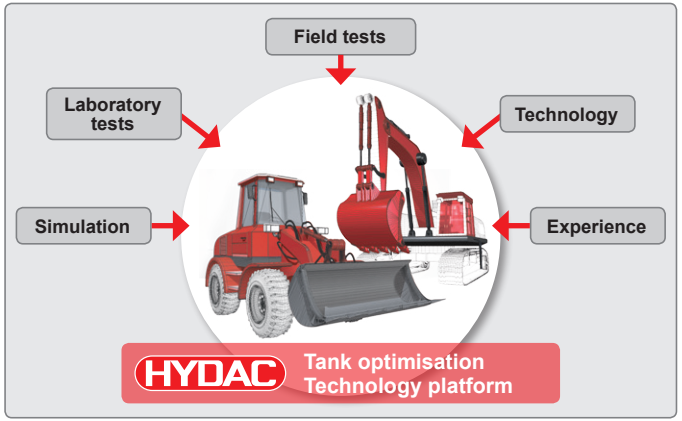
HYDAC Support/System Optimisation

Intelligent System Optimisation for Air Removal

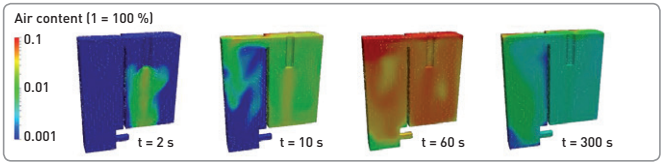
We use the following tools to develop the best individual solutions for your system:

- Many years' experience in the field of intelligent system optimisation for air removal and stimulating exchanges of information in this area
- Customised test rigs and measurement technologies analyse the air removal on subsystems and develop the optimum solution for your application
- Qualified engineers measure air removal from complete systems using field instruments
- Qualified engineers find and rectify any sources of air inclusion
- CFD flow simulations to find solutions
- Individual, space-saving complete tank systems (see also page 29) to prevent air inclusion in your system

Tank Optimisation – HYDAC Platform



In the HYDAC FluidCareCenter, our most experienced fluid technology specialists work on application-specific solutions



Multiphase bubble flow simulation in the tank

Return Line Filter for Tank Optimisation

In the field of tank optimisation with regard to degassing, HYDAC has succeeded in creating a filter series (in-to-out) which not only reduces the amount of air in the oil due to its specific degassing concept, but also allows for a significantly smaller tank design. For the OEM this means considerable cost savings (less oil) as well as less material usage and space requirements for the hydraulic tank. The filters are also equipped with quality protection features which do not permit operation with external elements. The intelligent QP version is supported by our HYDAC clogging indicator (HPT500) which identifies the use of original filter elements and displays an error message if external elements are used.

Advantages:

- Longer oil service lives due to active degassing
- Quality Protection ensures the use of original filter elements
- Lower Δp thanks to innovative Helios® fold geometry
- Lower maintenance costs (smaller tank/less oil)

... for Total Energy Optimisation

Pressure Transmitters/ Pressure Switches

In order to comply with the Directives on the reduction of engine exhaust emissions for mobile machines, hydraulic systems are today being developed with particular focus on the most efficient use of energy.

HYDAC offers pressure transmitters and electronic pressure switches which have been specially designed for the tough conditions in mobile hydraulics.
They are particularly suitable for the complex control tasks in such systems, e.g. positive control systems.

Advantages:

- Very robust sensor cell
- Small, compact design
- Available with increased functional safety/diagnostics
- Small temperature error
- Accuracy: ≤ ± 0.25 % FS typ.
- Excellent EMC characteristics

Universal Mobile Controller HY-TTC 500/90/60/30

The HY-TTC family meets all technical requirements for modern automotive electronics in the off-highway sector. It is part of a complete and compatible product family and is protected by a robust and extremely compact housing specially designed for the off-highway vehicle industry.

Performance features:

- **Functional safety PL d / SIL 2**
- Comprehensive I/O set, up to 98 I/O (38 PWM)
- Robust die-cast aluminium housing

I/O Expansion Modules HY-TTC 48X/48XS/30X/30XS

The HY-TTC series of I/O expansion modules provides an outstanding power balance combined with extremely compact design. They provide a simple extension of on-board electronics. The communication and integration takes place via CANopen according to CiA DSP 401. It enables inputs and outputs to be configured and parameterised via the control configuration of the available controller in a simple and uncomplicated way.

Performance features:

- **Up to PL c**
- Freely configurable Node-ID via pin
- Up to 48 I/O with up to 8 PWM outputs
- Robust and very compact housing

... for Total Energy Optimisation

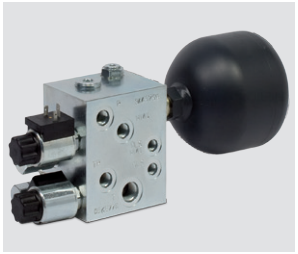
Load-Sensing Switching Valve

Load-sensing generally refers to load-sensing hydraulic controls. In this case the block is designed to charge an accumulator in the brake circuit quickly. When the accumulator is full, the valve is closed and when it is drained, the valve to the pump opens and the full pump pressure acts on the pump's LS line. The pump's displacement angle now switches to maximum in order to charge the accumulator quickly.

A built-in pressure relief valve protects the pump. An additional orifice dampens the load sense pressure signals.

Advantages:

- Pump protection built into the block
- Optimum damping of the system through use of bypass orifice
- Accumulator charging as required



Accumulator Charging Switch

HYDAC accumulator charging valves control the charging of the hydraulic accumulator within an adjustable switching range.

The combination of accumulator and accumulator charging valve means that pumps and motors on oil-hydraulic systems with fluctuating flow requirements can be downsized. This saves money and energy, and unnecessary heat generation is also avoided.

Application examples for mobile machinery:

- In the brake circuit
- For supplying the emergency steering

Advantages:

- Simple and optimum system adaptation through the use of valves with various fixed switching pressure differentials (12, 16, 21 %)
- Shut-off pressures are user-adjustable
- Low Δp characteristics
- The accumulator cannot discharge unexpectedly because the poppet valves are leak-free

Notes

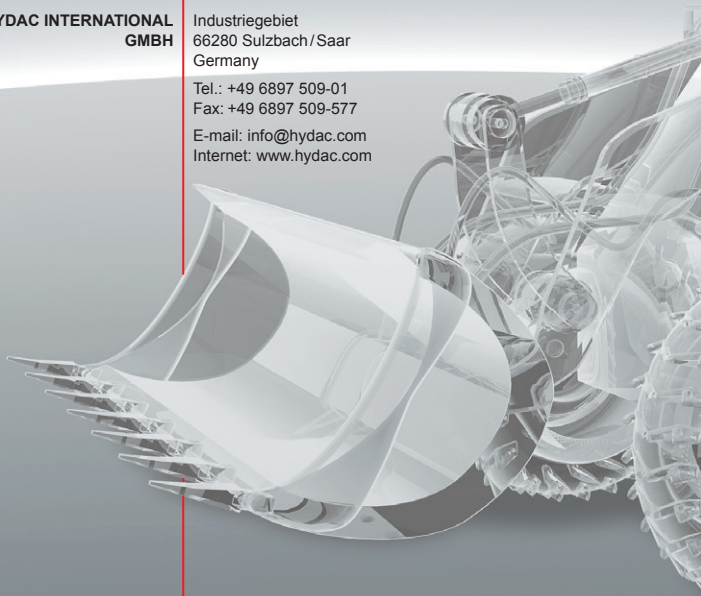
HYDAC INTERNATIONAL

HYDAC INTERNATIONAL GMBH

Industriegebiet
66280 Sulzbach / Saar
Germany

Tel.: +49 6897 509-01
Fax: +49 6897 509-577

E-mail: info@hydac.com
Internet: www.hydac.com



E 13.200.3 / 03.17