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at the IAA Commercial Vehicles 2008

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COVER STORY

Technology Trends at the IAA Commercial Vehicles 2008

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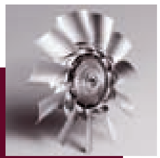
COVER STORY

DEVELOPMENT

SPECIAL



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I look forward to the many opportunities of meeting you this autumn, whether it is at the FISITA congress in Munich, the IAA in Hanover or the Autosalon in Paris.

Johannes Winterhagen
Wiesbaden, 19 August, 2008

Johannes Winterhagen
Editor-in-Chief

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Trend towards Clean and Fuel-Efficient Trucks

The IAA Commercial Vehicles 2008 in Hanover is a platform for numerous new presentations in the truck sector. The Mercedes Actros MP3 is celebrating its premiere at the show, the two Volvo AB subsidiaries Volvo Trucks and Renault Trucks are presenting their long-distance truck series, while MAN and Scania are focusing on their Euro 5 engines with exhaust gas recirculation – although the Munich-based company has also updated its light and medium-weight series. This report presents an overview.

1 Trend towards Automated Transmissions

There is a clear trend in the commercial vehicle sector towards automated transmissions. Across all manufacturers, the market share in the long-distance segment has reached more than 50 % in the meantime. The IAA Commercial Vehicles in Hanover will confirm this trend. The high transportation volume is faced with a falling number of drivers and therefore with drivers that are less well qualified. Automated transmissions with adapted characteristic maps help to avoid operating errors and to reduce fleet fuel consumption. Iveco already set the standard a few years ago by making its service and maintenance contracts for trucks with automated transmission much cheaper. Clutch service life guarantees of up to 800,000 km are evidence that automated transmissions can in fact reduce wear. The trend is currently towards automatic transmissions in other segments too. MAN is the first manufacturer to offer software for use in construction vehicles. Volvo is working on versions for distribution vehicles, as well as on applications for construction and heavy-duty vehicles.

2 MAN Nutzfahrzeuge Turns to EGR and Two-stage Turbocharging

At the IAA Commercial Vehicles in Hanover, MAN Nutzfahrzeuge is presenting its new common rail commercial vehicle engines, which comply with Euro 5 and the voluntary EEV standard without the use of AdBlue additive. The basis for the low emissions of the D08 CR, D20 CR and D26CR engines are exhaust gas recirculation and two-stage turbocharging. The engines comply with the strict emissions standard without the use of SCR technology. At the same time, MAN is expanding its range of engines with the addition of versions that meet the stringent EEV (Enhanced Environmentally Friendly Vehicles) standard – in the light and medium-weight trucks of the TGL and TGM series by using exhaust gas recirculation and in the heavy TGS and TGX series by means of SCR engines.

In order to achieve the Euro 5 / EEV standard, the engine developers at MAN are making use of lambda-controlled exhaust gas recirculation (EGR) with recirculation rates of 30 % and more and two-stage supercharging with indirect intermediate and main intercooling, as well as common rail technology with high injection pressures of up to 1,800 bar. Together with improved cooling of the recirculated exhaust gas, the high EGR rate ensures a lower temperature of the fresh charge/exhaust mixture in the combustion chamber of the cylinder. As a result, less NO_x is produced during combustion. Thanks to a new EGR control system with the aid of a lambda sensor, the optimum EGR rate is set for every operating point of the engine even under dynamic conditions. This has a favourable influence on the engine's fuel consumption. In addition to the new engines, MAN will also be presenting the completely revised vehicles of the TGL and TGM ranges in Hanover, **Figure 1**.

Both now bear the new family face that brings them into line with the heavy ranges. Technically speaking, it also conceals a great deal of aerodynamic fine-tuning to further minimise drag and wind noise. Further improvements can be found in the cab structure: the cab doors now have stronger frames and hinges that can withstand the increased loads of the so-called "shaker test".

The basic body structure of the TGL and TGM cabs has been maintained, and they are among the most spacious types on the market. New upholstery and trim materials further upgrade the interior,

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Figure 1: With the current model change for its TGL and TGM light and medium-weight series, MAN is harmonising the external design with that of the TGX/TGS long-distance series that was launched in 2007. New engines with exhaust gas recirculation comply with the Euro 5 standard and particularly low-emission EEV versions are available in some cases

and for long-distance drivers there is the option of a climate-controlled seat that has a temperature-controlled airflow through the seat cushion and seat back. A multi-function steering wheel is available for all vehicle types and an air conditioning system with automatic temperature control is an optional extra.

For the drive train, MAN is featuring new transmissions. The specialist for light solo trucks is the six-speed ZF 6 S 800 OR transmission, while for the medium-weight TGM with more powerful engines and for trailer operation, the nine-speed ZF 9 S 1310 OD manual transmission is standard equipment. As an option, the MAN TipMatic automated transmission offers driving comfort and effective relief for the driver in all situations. For engines with outputs of up to 162 kW, the transmission has six speeds, while in more powerful versions the transmission management system controls a twelve-speed basic transmission. For municipal vehicles and fire services, the TGM is available with a ZF 5 HP 502 six-speed automatic torque converter transmission. In future, this transmission will be offered via qualified conversion suppliers. As the first manufacturer in this class, MAN is offering an EBS brake system, with the option of integrating the ESP stability system for solo vehicles.

For its long-distance truck ranges, MAN is presenting numerous detail innovations, such as its LUKA air compressor with a disengageable clutch, which can achieve a saving of about 0.5 l of diesel per 100 km in typical long-haul operation. Unlike a conventional air compressor, which continues to operate and use energy even when the necessary air pressure in the reservoir has been reached, the LUKA compressor is disengaged. The LUKA system has a compressed air-operated multi-plate clutch between the air compressor crankshaft and the diesel engine drive shaft, and is controlled by a solenoid valve. In addition to a significant reduction in fuel consumption, LUKA ensures a longer service life, oil ejection into the braking system is reduced and noise emissions are lower.

In the "Fleet" version of the long-distance range, the TipMatic automated transmission will be standard equipment in future. Manual intervention is possible only when pulling away and in overrun operation or when the system has a defect. Kickdown gear commands with their effect of increasing fuel consumption are not possible. This significantly reduces fleet fuel consumption. MAN is the first manufacturer to offer ESP, which has become successfully established on the market, as standard equipment in a commercial vehicle.

3 Volvo Focuses on Safety

When renewing the FH/FM range, Volvo focused above all on safety. An important part of Volvo's strategy is to relieve drivers of the stress of certain tasks but not to take away their responsibility. Volvo is the first manufacturer in Europe to develop a driver warning system that uses a camera to monitor how the vehicle is being driven in relation to the road markings, **Figure 2**.

If the vehicle's progress is perceived as erratic, the system warns the driver by means of an audible signal and a text message. If the erratic driving pattern continues, the driver is alerted to stop and take a break.

Another frequent cause of truck accidents is restricted vision. Blind spots, bends, darkness and poor visibility restrict drivers' control over their vehicles. The new Lane Changing Support system from Volvo offers a "third eye". A radar sensor helps the diver to detect other vehicles in the blind spot on the passenger side. The driver is alerted by a warning light on the A-pillar and an audible signal, **Figure 3**.

To improve safety during cornering, Volvo is offering the option of cornering lights that illuminate the road edge when turning at low speed. At speeds of less than 30 km/h, the cornering light is automatically directed to the correct side when the turn indicator light is actuated. A further addition to the safety package is a rain sensor. It measures the intensity of the rain and automatically adapts the speed of the windscreen wipers. Until now, ESP was only available for tractor-trailers. Now, Volvo is the world's first manufacturer to introduce ESP for 6x2 trucks with a trailer, **Figure 4**.

By braking the wheels of the trailer in certain situations, ESP stabilises the whole truck including the trailer, thus preventing tipping and jack-knifing.

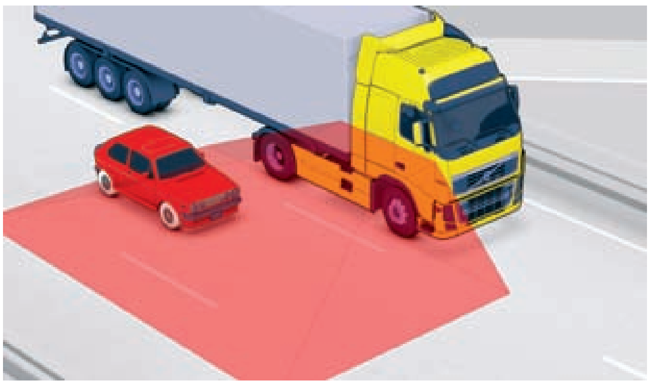


Figure 2: Volvo is the first truck manufacturer to introduce a Lane Changing Support system. An ultrasound broadband sensor monitors the traffic space directly to the right of the truck. If an obstacle is detected, the driver is warned by a visual signal in the A-pillar

Figure 3: The new FH is the first truck to feature cornering lights. In the Volvo system, the cornering light is produced by a simple mirror installed at a 90° angle in the headlight. The light, which is activated as soon as the driver actuates the turn indicator, is conspicuous to warn pedestrians and cyclists that the truck may be about to turn

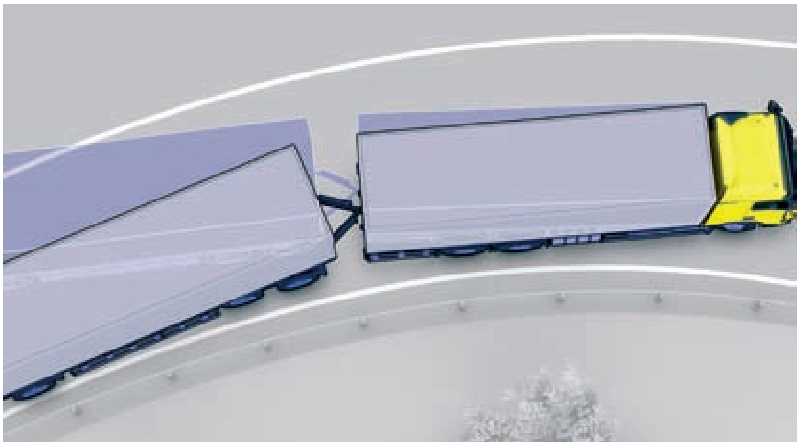


Figure 4: All European truck manufacturers in the meantime offer ESP in tractor-trailer combinations. Volvo is now the first to install ESP in a 6x2 truck with a trailer. As far as driving dynamics are concerned, this combination is difficult to handle due to its two pivot points. What is more, there is no electronic connection between most trucks and trailers

Volvo has developed a completely new 11-l engine for its FM range of trucks. The engine has been specially developed for applications in which the vehicle weight plays an important role, such as tanks and bulk goods transport, **Figure 5**. The new engine is approximately 140 kg lighter than the larger D13 engine. This allows a high load capacity. The D11 engine also offers a high power output and a low fuel consumption. Due to SCR, the D11 engine complies with both the Euro 4 emissions standard and the future Euro 5 standard. The engine is being launched in two power versions, one with 287 kW and 1,880 Nm of torque and the other with 316 kW and 2,100 Nm of torque. A high power output is developed at both high and low revs. The most economical engine speed range is between 1,050 and 1,500 rpm. In this range, 95 % of maximum torque is available. The engine is equipped as standard with the automated I-Shift transmission.

The design of the 11-l version of the Volvo FM is the same as the rest of the FM range. The external improvements include new headlights and sun visors. The interior of the cab has been fully redesigned to ensure optimum conditions for safe driving and to provide flexible storage space. In addition, Volvo's low entry steps provide extra comfort for drivers who often have to get in and out of the cab during their working day.

The Volvo FM is now also available with a new Globetrotter LXL cab. This was developed to offer even more space and additional comfort. Compared to the Globetrotter cab of the Volvo FM, the LXL version offers an additional 150 mm of headroom.

The Volvo FM with an 11-l engine is available as a 4x2 and 6x2 articulated tractor. Maximum permissible overall weight is 40 t. The Volvo FM is approved for the transport of hazardous goods. The new cab interior of the FH and FM truck series from Volvo was developed on the basis of various surveys among drivers and haulage companies and offers a working environment with optimum functionality, more space and increased comfort, **Figure 6**.

Drivers frequently say that they would like a greater standing height and more freedom to move in the cab. In order to create a better impression of space and to offer more freedom of movement when standing, the storage lockers above the driver's seat have been redesigned. The distance between the controls for the I-Shift and Powertronic transmissions to the driver's seat has been slightly increased. A new feature is a new lounger-type bunk bed with a reclining backrest, **Figure 7**.

The storage space under the bed has been enlarged and is now more easily accessible. The shape of the dashboard has also been adapted to improve storage space. Further improvements include a swivelling passenger seat and the possibility to install a flat screen television. The new lighting system now features a dimmer function to adapt the lighting level to individual needs.

4 Mercedes-Benz Enhances the Interior and Exterior

The changes on the new Mercedes-Benz Actros are somewhat less extensive, **Figure 8**. New features include the now standard equipment 12-speed automated

Figure 5: Volvo is equipping the heavy midsize class in future with a new 11-l inline six-cylinder engine with up to 430 bhp. Due to its increased load capacity, the FM is particularly interesting for weight-sensitive tank and silo transport. With the new Globetrotter cab, the new FM is also suitable for international use

Figure 6: In the FH model facelift, Volvo is above all emphasising the safety aspect. Lane change assistant, cornering lights and ESP for trucks with trailers are world premieres in the commercial vehicle sector. For the driver, there is a new interior with more storage space, ergonomic dashboards and more comfortable bunks

transmission and around a dozen large and small product enhancements for the interior and exterior.

The new Actros is equipped as standard with a Mercedes PowerShift 2 transmission in a further developed form for all on-road applications. Mercedes PowerShift 2 now has an integrated inclination sensor and a refined gear-change strategy. The incline of the road is constantly monitored and compared with the vehicle speed and the position of the accelerator pedal, thus allowing the gear shift controller to issue optimum gear-change commands for the situation in hand. The new Mercedes PowerShift 2 transmissions are all direct shift transmissions, and replace the previous fast shift transmissions in all V8 power classes, with the exception of the 6x4 powertrains. PowerShift 2 also has the following driving programmes: Power Mode, Eco-Roll Mode, Manoeuvring Mode and Rocking Mode.

The sophisticated sensors on the countershaft and transmission main shaft allow the transmission's gearshift computer to change gear more smoothly yet noticeably faster, thus reducing power-flow interruption times accordingly. A new feature to be fitted as standard from the end of 2008 is the battery status indicator. This allows the driver to check the battery status before, during and after every trip by going into the in-strument-cluster menu and calling up a bar chart that displays the various parameters. This bar chart also indicates the expected lifetime of the battery. The E-APU (Electronic Air Processing Unit), which is fitted as standard and integrated into the electronic data-exchange network via CAN bus, is aimed at reducing fuel consumption. In this system, the pressure in the brake circuits is increased and additional pressure is stockpiled during braking. Thanks partly to the omission of the separate pressure vessel in brake circuit 3 (spring brake circuit), the system reduces weight by around 20 kilograms and therefore pays immediate dividends in terms of payload. It also speeds up air spring lifting times by up to 20 %. Further features integrated in the E-APU include intelligent control of the air com-pressor which, in the new Actros, only operates when power loss is low, i.e. in deceleration (overrun) mode, especially when driving downhill.

The Mercedes-Benz engineers have also turned their attention to the water pump. A special Linnig clutch has been introduced to enable the pump to operate more efficiently. In partial-load mode, it runs at a lower operating speed and consumes less power. During full-load operation, the clutch is rigidly connected by electromagnetic means and thus achieves the desired, full delivery rate. The system is due to be introduced in 2009, initially for the 320-kW/435-bhp engine. This measure is said to reduce fuel consumption by up to one percent.

In the interior, for the first time in a truck, an infinitely variable level control system with retaining straps ensures that the top bed remains horizontal at

Figure 7: A newly designed frame above the windscreen provides more freedom of movement for the driver. An innovative feature is the reclining backrest of the lower bed. In addition, Volvo is providing the FH with more storage space and a variable interior lighting concept

Figure 8: Rather less extensive modifications to the Mercedes-Benz Actros

all times. The lower bed now also features a flexible slatted base with an adjustable head section. Access to the top and bottom bed as well as to the storage compartments beneath the bed has also been improved – thanks to the new seat unlocking mechanism on the upper side of the air-sprung seat's backrest. The optionally available rain and light sensors are the same as those used in the Mercedes-Benz E-Class passenger car and are a useful aid for the driver. Comfort is also enhanced by the optionally available, temperature-controlled auxiliary air-conditioning unit. In the L and Megaspace cabs, the new sunblind, which is standard on the driver's side and optional on the co-driver's side, prevents dazzling by the sun while driving and during breaks. Other new features include an adjustable and retractable shaving mirror – fitted as standard on the upper storage compartment – and the equally easy-to-stow folding table, which is available as an option on the co-driver's side. Both the L cab and the Megaspace cab for the new Actros feature a built-in towel rack with coat hooks, which can also be used for drying washing.

The chassis and suspension system of the Actros has also been improved. Optimised steering further improves handling in semitrailer tractors with air suspension. Thanks to a smaller-diameter torsion bar, modi-fied control arms, a new valve opening curve and a reduced steering ratio, the steering is now even more direct.

The new Actros is the first and, to date, only standard-production truck to offer Active Brake Assist as an option. Active Brake Assist is based on the Telligent proximity control system. In contrast to a straight proximity control system, which automatically keeps a set safety margin between the truck and the vehicle ahead, Active Brake Assist initiates emergency braking automatically if there is an acute risk of a head-to-tail collision with a vehicle in front.

A radar system detects moving obstacles in front of the truck while continuously calculating the difference in speed between the Actros and the vehicle in front. If the traffic situation does not change and an accident seems unavoidable, the driver first receives a visual warning, followed by an audible warning. If the risk of a collision increases, partial braking is initiated and 30 percent of the full braking power is applied. If the driver still fails to react, the system applies the full braking power automatically.

5 Renault Sends its Magnum Into a New Dimension

With the new-generation Renault Magnum, the classic truck that was launched in 1991 is moving into a new dimension, **Figure 9**. Back in 1991, it was the first long-distance truck to have a flat floor and an innovative design. For 2008, the development objectives were more volume, more storage space and more equipment – although the facelift is restricted to the exterior and above all to the interior.

Standard equipment for the new generation will include a new tinted Viscope sunshade with a chrome strip, LED marker lights and pre-equipment for connecting an additional row of headlights, a bar under the windscreen bearing the Renault name to emphasis the lines of the cab, a two-colour radiator grille, a three-part front spoiler with a glass fibre polyamide step and a 20 cm higher cab with an interior height of more than 2 metres, **Figure 10**.

The Multipass concept, which comes as standard, offers a carefully designed

Figure 9: The model facelift measures on the Magnum are restricted exclusively to the cab. The powertrain with the two inline six-cylinder engines with just under 13 litres and 460 or 500 bhp and a manual 16-speed transmission and the option of an automated 12-speed transmission were taken over from the predecessor

Figure 10: In the latest generation of the Magnum, the French company is equipping its flagship with a new high roof. The storage compartment arrangement above the windscreen will in future offer more than 200 litres of storage space

functional layout featuring a suspended driver's seat, a swivelling passenger seat, a fold-up table and a modular rest area with one or two bunks. In the "Privilège" version, the cab is equipped as standard with air conditioning, auxiliary heating, remote door control, and a remote controlled radio/CD player. The front storage compartment within reach of the driver has been tripled in volume and now offers a total of 263 l. At the back of the cab there is a particularly large storage compartment with an overhead folding mechanism in an airline design, **Figure 11**.

The cab of the new Magnum also features an improved, modular interior lighting system with four white 21 W ceiling lights, two 71 W ceiling lights for night driving and two fixed or mobile reading lights, depending on the version.

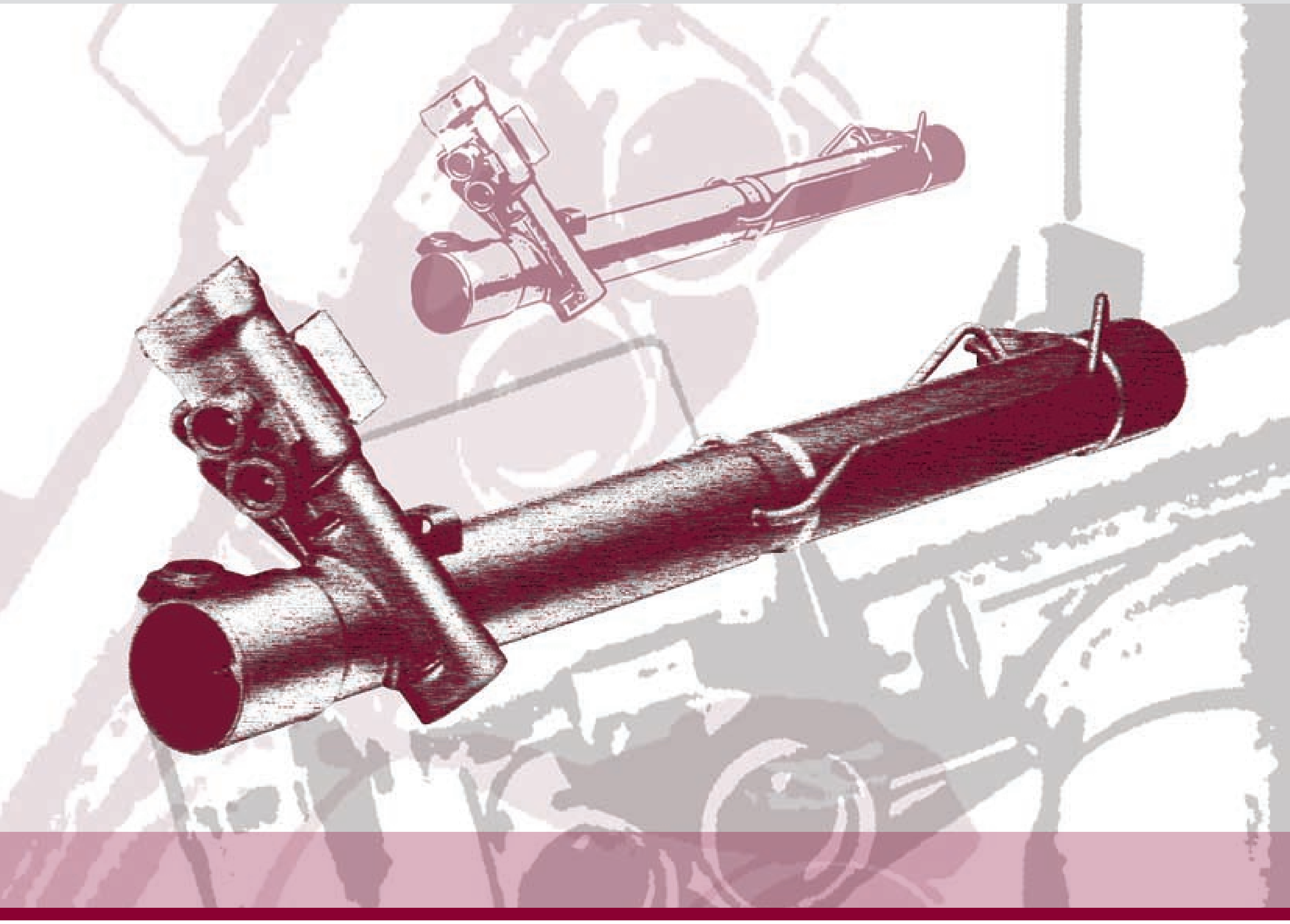
Figure 11: The working and living areas in the high-roof cab of the Magnum "New Generation" are separated both in their colours and in their equipment. Depending on the version, the Magnum has an adaptable seat/bunk arrangement that can be converted as required

6 Conclusion

The latest new presentations at the IAA cannot conceal the fact that 50 % of the future potentials for reducing fuel consumption will have to come from greatly improved aerodynamics and other improvements to minimise rolling resistance. The development of the classic front-steered truck offers hardly any room for further significant improvements. The example of the Volvo FH shows that an aerodynamically favourable position of the windscreen automatically results in a loss of space in the cab. In view of the increasing proportion of long-distance operation and longer trip durations, this is actually an unacceptable situation. The potentials offered by spoilers, body fairings and wheel design have also been fully exploited. There are good reasons why aerodynamic engineers like Linus Hjelm from Volvo Trucks are calling for amendments to the European regulations on truck lengths in order to create as much space as possible for the driver while at the same time allowing sensible aerodynamic measures to be taken without reducing load space. A realistic scenario could be to use cameras instead of side mirrors. Although the technology already exists, the regulations would have to be changed before they can be used in practice.

One effective means of improving the aerodynamic properties would be to provide a smooth aerodynamic floor for the tractors, and especially for the trailers. An interesting approach is the "Transport Concept" from Iveco. It is an aerodynamically optimised tractor-trailer combination with an extended 15-metre trailer that is more than 15 % more fuel-efficient than a standard combination.

A further fuel-saving potential is offered by the tyres. According to Michelin, their new Energy 3 "Green" tyre saves up to a litre of fuel per 100 km. For construction vehicles, Duraseal technology from Goodyear is an interesting concept: Duraseal automatically seals damage to tyres. ■



Steering Systems with Steel Housings in Passenger Cars and Light Commercial Vehicles

The deployment of welded steel housings has led to a rethinking of steering gear development and production, as they allow greater design flexibility and faster fulfilment of special design requirements from car makers. The rack-and-pinion steering gear with a steel housing increases steering comfort and, due to the use of an adjustable vane pump, reduces fuel consumption and CO_2 emissions. Tedrive Steering has gained experience with steel housings in passenger cars and is also making use of this technology for light commercial vehicles.

1 Potential of Steering Systems with Steel Housings in LCVs

Light commercial vehicles (LCVs) play an important role in the competition for sales among most automotive manufacturers today. This role goes beyond their initial niche existence. What is more, LCVs are enjoying growing popularity with end-customers, not only in the commercial segment. Light commercial vehicles place similar design requirements on the chassis as passenger vehicles. Among other things, this is a consequence of more powerful engines and the corresponding increase in top speeds. Demands for a more ergonomic workplace for drivers and passive safety that is comparable to passenger cars are vital considerations in the development of such vehicles. The steering gear is a basic element of these comfort and safety attributes relating to the front axle and, with its steel steering gear housing, Tedrive Steering has met this challenge, **Figure 1**.

Steel housings are more rigid and durable than the die-cast aluminium housings typically used until now, as they deliver improved quality by eliminating porosity. Consequently, stiffer steel housings noticeably improve steering precision.

Economic and environmental compatibility are equally important aspects for car manufacturers and vehicle owners alike in the development of new cars. OEMs look for cost-efficient solutions regarding sourcing and manufacturing for low- and high-volume production alike. These solutions need to offer the best technical attributes in terms of performance, weight, packaging, lifecycle etc., and at the same time have to address increasingly strict environmental regulations.

Vehicle owners look for cars that generate a minimum of follow-up costs while offering maximum driving performance over the entire lifecycle. With regard to steering gears, this means lower costs for engineering, materials and production, but also reduced fuel consumption and lower CO_2 emissions.

The solution is a steel housing with a solid welded construction that withstands operating pressures of 200 bar and above. The welded construction uses the flexibility of the joining technology and the improved strength properties of steel.

As a result, new ranges of operating pressures for rack-and-pinion steering gears can be achieved while at the same time offering realistic fuel economy improvements and reduced CO_2 emissions of up to 25 %. In combination with modifications to the steering pump component, additional reductions in fuel consumption would even be possible. By using a welded steering housing construction, as already successfully introduced in the passenger car segment, even individual low-volume and minimum-volume series within one vehicle platform could be addressed at a lower cost. This offers entirely new design opportunities to the engineering community. Changing over to steel, however, does not mean weight drawbacks, since the required wall thickness for steel is considerably less than with aluminium.

2 Current Steering Systems in Light Commercial Vehicles

In light commercial vehicles, two different basic principles of steering gears are used: a rack-and-pinion steering gear or a re-circulating ball steering gear.

The re-circulating ball steering gear offers many design opportunities for the steering trapezoid and, as a result, design possibilities for steering kinematics and toe-in changing curves. The disadvantag-

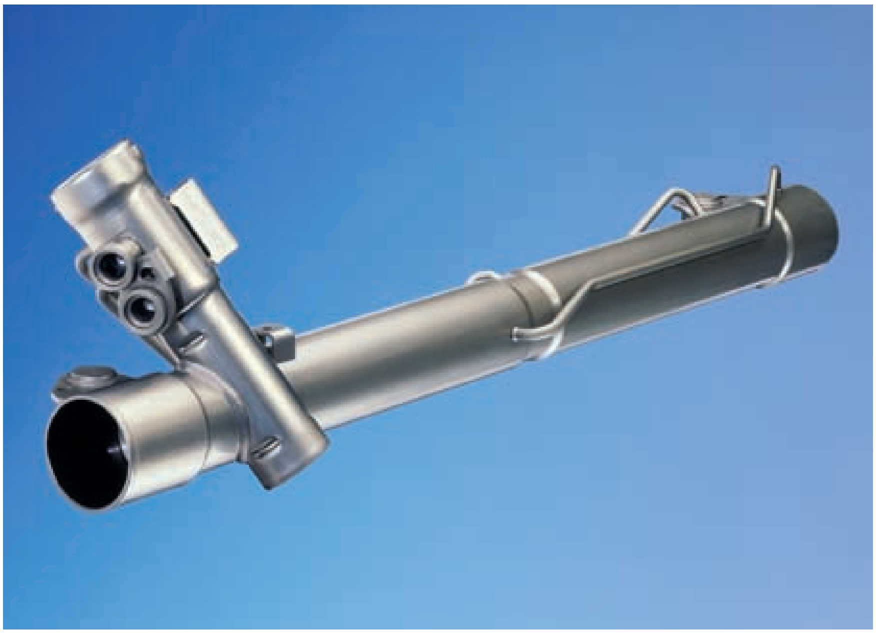


Figure 1: Steel housing for steering gears

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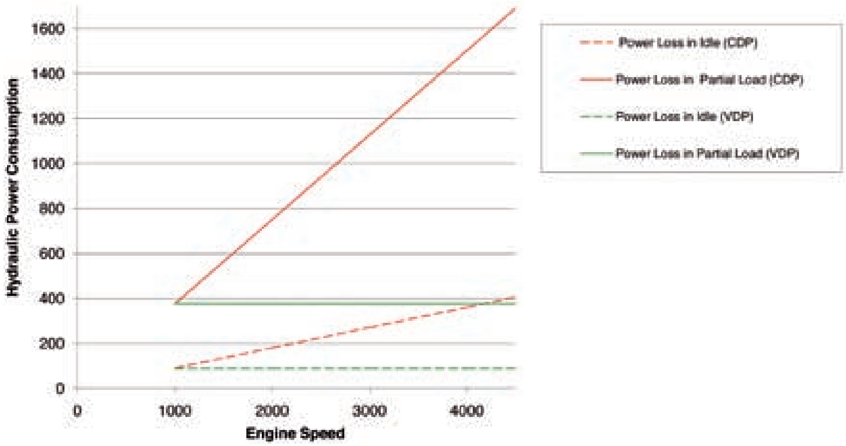

Figure 2: Power consumption of a constant displacement pump (CDP) versus a variable displacement pump (VDP)

es of the re-circulating ball steering gear is its higher elasticity and compliance due to the use of the steering linkage and the resulting higher steering flexibilities with regard to steering responsiveness. This in particular influences the steering sense in the centre range. In addition, re-circulating ball steering is a technically more complex system with a weight disadvantage over a comparable rack-and-pinion steering system. This results in the following advantages for rack-and-pinion steering gears: better steering feel/response, lower weight and a reduced number of components.

Besides the driving characteristics, the influence of the steering system on fuel consumption is facing an increasing level of attention. In the case of hydraulically assisted steering systems, the power required for the steering assist is generated by a hydraulic pump, which is driven by a belt from the engine. The hydraulic energy required is supplied by vane pumps or piston pumps that operate as constant or variable displacement pumps. The application of vane pumps with a constant displacement is the preferred solution due to the cost advantage. The power consumption of a constant displacement pump depends on the delivery flow Q (depending on the speed of rotation in the operating state) and the system pressure P. The effective delivered flow is the product of the delivery volume per rotation and the engine speed. The constant flow provided for the steering system is only a fraction of the actual delivery flow. For this reason, the absorbed hydraulic power is much higher than the effective power required for a steering system, which results in a significant disadvantage for the usage of constant displacement pumps, **Figure 2**.

Due to the hydraulic power required by constant displacement pumps, the average fuel consumption increases under average driving conditions by approximately 0.6 l to 0.8 l per 100 km. For an estimated mileage of 50,000 km per year and based on an average fuel price of 1.20 euros per litre, the servo steering system causes additional fuel costs in the range of 360 euros to 480 euros per year.

An effective reduction in fuel consumption can be achieved by applying a variable displacement pump (VDP). Fuel savings of up to 40 % are realistic compared to conventional constant displacement pumps (CDP). The main design difference between constant displacement pumps and variable displacement pumps is the layout of the stator. In constant displacement pumps, the stator is designed as a double eccentric stator, which does not allow an adjustable displacement. The variable displacement pump combines a concentric stator with initial eccentricity to the rotor, **Figure 3**. The initial eccentricity defines the maximum geometrical delivery volume of the steering pump. Under operating conditions, the eccentricity of the stator is adjusted by an oil flow delivered through a control pipe, thus creating a pump displacement that delivers a constant volume flow independent of the engine speed. There are obvious advantages to this. By controlling the adjustment of the eccentricity, an effective volume flow (added inner pump leakage) is generated and the power consumption dependent on the engine speed is significantly decreased.

Another fuel-saving potential of the adjustable vane pump is the operating pressure limitation of the steering system by decreasing the delivery flow. Therefore, at the point of maximum operating pressure, the stator is adjusted in a zero stroke position and the pump delivers the required volume flow at a constant pressure to balance the gap and valve leakage.

An even greater fuel-saving potential is offered by a reduction in the constant volume flow with a simultaneous increase in the maximum system pressure. With

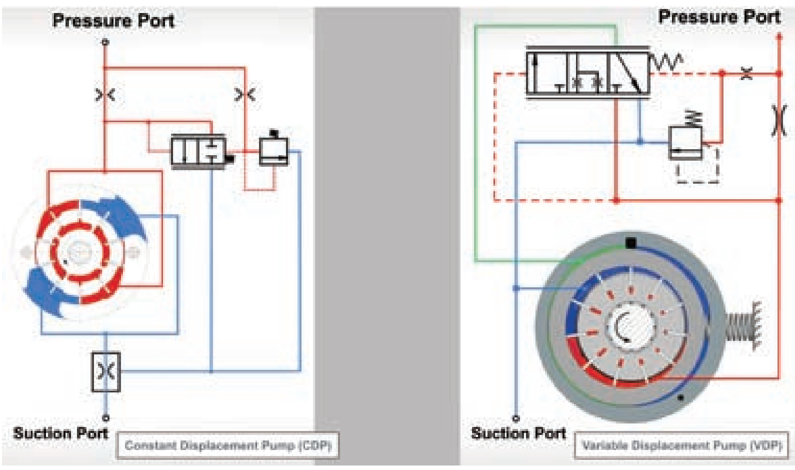

Figure 3: Operating principle of a constant displacement pump (CDP) versus a variable displacement pump (VDP)

the same maximum power, the effective average power is decreased linearly to the reduction in the effective volume flow.

3 Application-Optimised Steering System with a Steel Housing

In the development of new vehicles, car makers are faced with a dilemma. Cost pressure calls for large platform solutions, but the vehicle production volumes that are forecast may not justify a platform solution. Alternatively, the solution is to use modular, standardised components and systems that account for volume effects. However, a key disadvantage of the deployment of modular components is that tailor-made solutions are difficult to accomplish. This results in compromises being made. A better solution would be to use components that allow for application redesign until the optimum solution is achieved, but without major cost impacts. In the case of steering gears in particular, the flexibility of this engineering approach is the preferred solution, because it supports the necessary modifications for different front-axle loads across the same vehicle class with regard to power-assist performance, gear size and weight.

The welded steel design enables a simple adaptation of the steering gear to the different subframe structures, because, in the event of design changes, only the welded fixtures need to be modified. Modifications to the expensive aluminium die-casting tools, which were necessary until now, are no longer required. Compared to the deployment of conventional steering gears with an aluminium housing, this leads to considerable cost savings. The benefit of increasing the maximum system pressures from 150 bar to 200 bar not only allows smarter packaging but reduces steering system-related CO_2 emissions.

Referring to the above-mentioned modifications as well as the increase in the maximum operating pressures and the reduction in the effective volume flow, it is possible to optimise the effective power consumption of the steering system. Because of the increase in maximum operating pressure from 150 bar to 200 bar and with the retention of all relevant parameters, it is possible to reduce the average power consumption and thus the CO_2 emissions by an additional 25 % on the system level. The precondition is that the ancillary systems (pipes, seals, fittings, etc.) are adapted to the new specifications.

Figure 4: Tedrive passenger car steering gear with a steel housing

4 Steel Steering Gear Housings for Extended Technical Requirements

Today, Tedrive's steel steering gear housing already meets the needs of its customers for many different applications in passenger cars, minivans and Sport Utility Vehicles (SUVs), **Figure 4**. The development of an innovative steering gear concept was an essential task in the performance specifications of the development order. The specifications included the fulfilment of the different requirements in terms of design, functionality and packaging for a vehicle platform ranging from a saloon and an estate car to a minivan and an SUV. A challenge was the reduced packaging space caused by the variety of engine and powertrain versions (petrol or diesel engine, manual or automatic transmission, five-speed or six-speed gearboxes, front-wheel or all-wheel drive). A total of 28 different applications were developed in an effort to find individual steering identities and driving dynamics for each of the vehicle segments. The different versions do not only vary in the hydraulic characteristics. The installation angle, bracket position, track width, steering ratio and interface position to the steering column are also different.

With regard to the cost-effective implementation of high-volume production, conventional and effective manufacturing processes were investigated but were rejected because of the high costs per unit and for the associated tooling. Close collaboration with the customer led to the development of a totally new concept that supports both product flexibility and cost-effectiveness while at the same time ensuring the necessary product robustness for all vehicle platform derivates, including off-road vehicles.

The cost-effective processing of commercial precision-tube, press and formed parts in combination with the different welding, forming and joining processes led to the desired characteristics of the steel housing. Cutting machining was only required in the high-precision bearing and sealing areas of the valve tower.

Most importantly, the change from aluminium to steel does not involve a weight disadvantage for the housing. The wall thickness of the steel housing design has been significantly reduced compared to the conventional aluminium design. This leads to an additional advantage for all-wheel-drive versions, which would have been very difficult to achieve by a conventional steering gear design.

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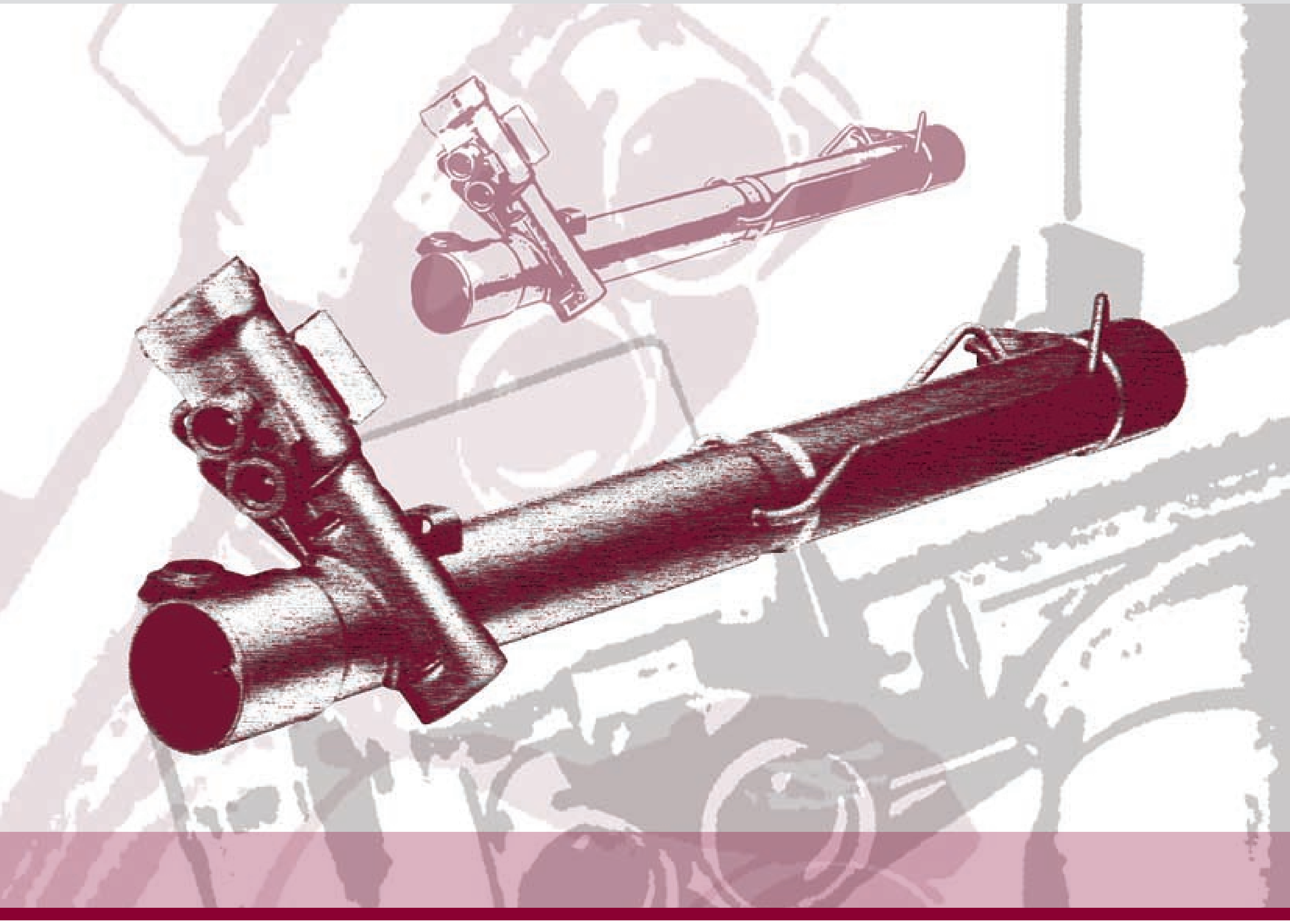
5 Summary

The benefits of a steering gear housing made of steel include more flexible integration, cost advantages due to the welded construction and the ability to reduce CO_2 emissions. This can be achieved by increasing the maximum system operating pressure. In combination with a variable displacement pump, a higher fuel-saving potential can be identified, thus enabling reductions in fuel consumption and CO_2 emissions. A further advantage for the customer is the significant improvement in the overall vehicle efficiency.

Advantages can be expected with regard to the assumed total weight reduction, crash performance and the improvement in the structural stiffness of the vehicle's front-end. These are additional potentials for further vehicle optimisation in the LCV segment that have not yet been exploited. For today's challenges in vehicle design, this opens up totally new approaches to engineering, and an increased interest from vehicle manufacturers can be observed. ■



Steering Systems with Steel Housings in Passenger Cars and Light Commercial Vehicles

The deployment of welded steel housings has led to a rethinking of steering gear development and production, as they allow greater design flexibility and faster fulfilment of special design requirements from car makers. The rack-and-pinion steering gear with a steel housing increases steering comfort and, due to the use of an adjustable vane pump, reduces fuel consumption and CO_2 emissions. Tedrive Steering has gained experience with steel housings in passenger cars and is also making use of this technology for light commercial vehicles.

1 Potential of Steering Systems with Steel Housings in LCVs

Light commercial vehicles (LCVs) play an important role in the competition for sales among most automotive manufacturers today. This role goes beyond their initial niche existence. What is more, LCVs are enjoying growing popularity with end-customers, not only in the commercial segment. Light commercial vehicles place similar design requirements on the chassis as passenger vehicles. Among other things, this is a consequence of more powerful engines and the corresponding increase in top speeds. Demands for a more ergonomic workplace for drivers and passive safety that is comparable to passenger cars are vital considerations in the development of such vehicles. The steering gear is a basic element of these comfort and safety attributes relating to the front axle and, with its steel steering gear housing, Tedrive Steering has met this challenge, **Figure 1**.

Steel housings are more rigid and durable than the die-cast aluminium housings typically used until now, as they deliver improved quality by eliminating porosity. Consequently, stiffer steel housings noticeably improve steering precision.

Economic and environmental compatibility are equally important aspects for car manufacturers and vehicle owners alike in the development of new cars. OEMs look for cost-efficient solutions regarding sourcing and manufacturing for low- and high-volume production alike. These solutions need to offer the best technical attributes in terms of performance, weight, packaging, lifecycle etc., and at the same time have to address increasingly strict environmental regulations.

Vehicle owners look for cars that generate a minimum of follow-up costs while offering maximum driving performance over the entire lifecycle. With regard to steering gears, this means lower costs for engineering, materials and production, but also reduced fuel consumption and lower CO_2 emissions.

The solution is a steel housing with a solid welded construction that withstands operating pressures of 200 bar and above. The welded construction uses the flexibility of the joining technology and the improved strength properties of steel.

As a result, new ranges of operating pressures for rack-and-pinion steering gears can be achieved while at the same time offering realistic fuel economy improvements and reduced CO_2 emissions of up to 25 %. In combination with modifications to the steering pump component, additional reductions in fuel consumption would even be possible. By using a welded steering housing construction, as already successfully introduced in the passenger car segment, even individual low-volume and minimum-volume series within one vehicle platform could be addressed at a lower cost. This offers entirely new design opportunities to the engineering community. Changing over to steel, however, does not mean weight drawbacks, since the required wall thickness for steel is considerably less than with aluminium.

2 Current Steering Systems in Light Commercial Vehicles

In light commercial vehicles, two different basic principles of steering gears are used: a rack-and-pinion steering gear or a re-circulating ball steering gear.

The re-circulating ball steering gear offers many design opportunities for the steering trapezoid and, as a result, design possibilities for steering kinematics and toe-in changing curves. The disadvantag-

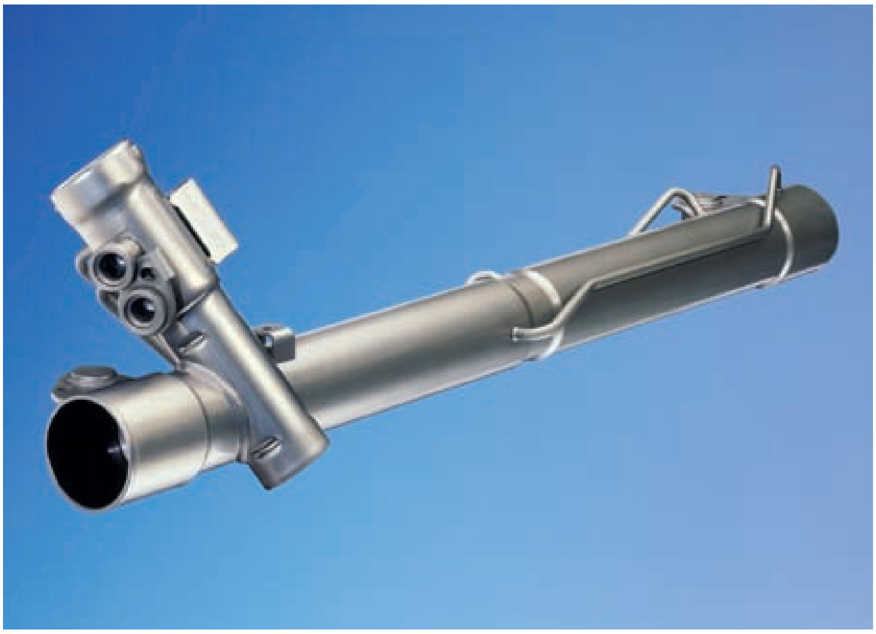


Figure 1: Steel housing for steering gears

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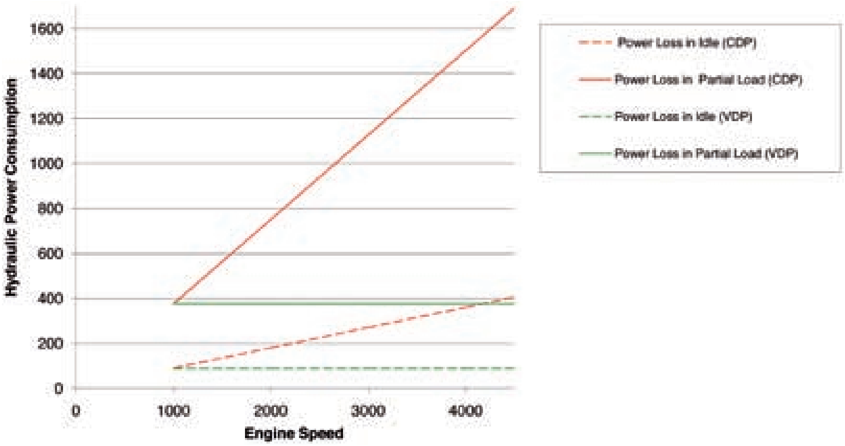


Figure 2: Power consumption of a constant displacement pump (CDP) versus a variable displacement pump (VDP)

es of the re-circulating ball steering gear is its higher elasticity and compliance due to the use of the steering linkage and the resulting higher steering flexibilities with regard to steering responsiveness. This in particular influences the steering sense in the centre range. In addition, re-circulating ball steering is a technically more complex system with a weight disadvantage over a comparable rack-and-pinion steering system. This results in the following advantages for rack-and-pinion steering gears: better steering feel/response, lower weight and a reduced number of components.

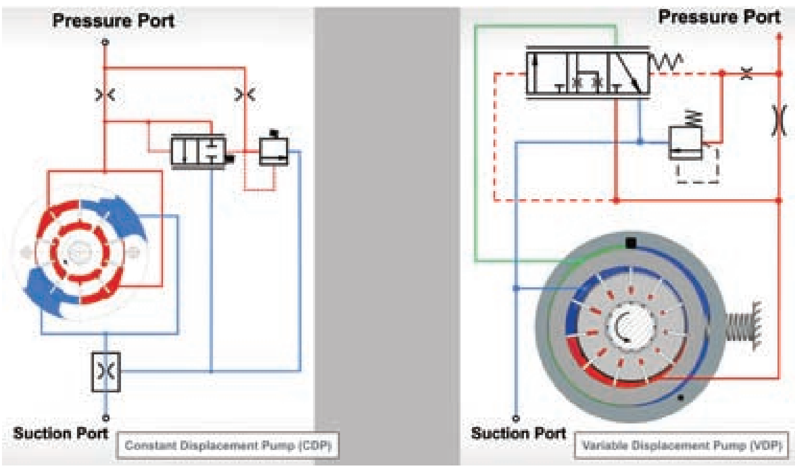
Besides the driving characteristics, the influence of the steering system on fuel consumption is facing an increasing level of attention. In the case of hydraulically assisted steering systems, the power required for the steering assist is generated by a hydraulic pump, which is driven by a belt from the engine. The hydraulic energy required is supplied by vane pumps or piston pumps that operate as constant or variable displacement pumps. The application of vane pumps with a constant displacement is the preferred solution due to the cost advantage. The power consumption of a constant displacement pump depends on the delivery flow Q (depending on the speed of rotation in the operating state) and the system pressure P. The effective delivered flow is the product of the delivery volume per rotation and the engine speed. The constant flow provided for the steering system is only a fraction of the actual delivery flow. For this reason, the absorbed hydraulic power is much higher than the effective power required for a steering system, which results in a significant disadvantage for the usage of constant displacement pumps, **Figure 2**.

Due to the hydraulic power required by constant displacement pumps, the average fuel consumption increases under average driving conditions by approximately 0.6 l to 0.8 l per 100 km. For an estimated mileage of 50,000 km per year and based on an average fuel price of 1.20 euros per litre, the servo steering system causes additional fuel costs in the range of 360 euros to 480 euros per year.

An effective reduction in fuel consumption can be achieved by applying a variable displacement pump (VDP). Fuel savings of up to 40 % are realistic compared to conventional constant displacement pumps (CDP). The main design difference between constant displacement pumps and variable displacement pumps is the layout of the stator. In constant displacement pumps, the stator is designed as a double eccentric stator, which does not allow an adjustable displacement. The variable displacement pump combines a concentric stator with initial eccentricity to the rotor, **Figure 3**. The initial eccentricity defines the maximum geometrical delivery volume of the steering pump. Under operating conditions, the eccentricity of the stator is adjusted by an oil flow delivered through a control pipe, thus creating a pump displacement that delivers a constant volume flow independent of the engine speed. There are obvious advantages to this. By controlling the adjustment of the eccentricity, an effective volume flow (added inner pump leakage) is generated and the power consumption dependent on the engine speed is significantly decreased.

Another fuel-saving potential of the adjustable vane pump is the operating pressure limitation of the steering system by decreasing the delivery flow. Therefore, at the point of maximum operating pressure, the stator is adjusted in a zero stroke position and the pump delivers the required volume flow at a constant pressure to balance the gap and valve leakage.

An even greater fuel-saving potential is offered by a reduction in the constant volume flow with a simultaneous increase in the maximum system pressure. With



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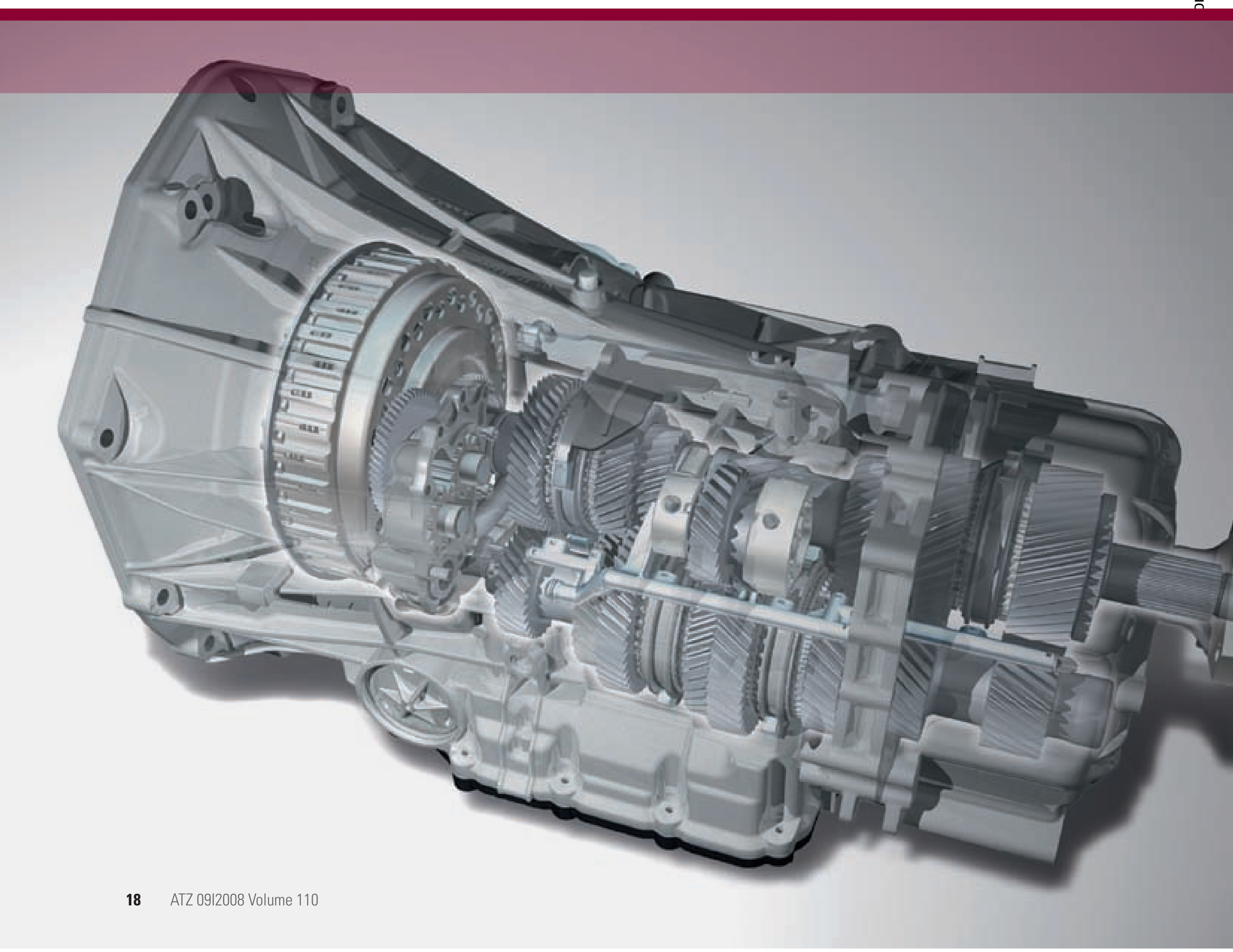

1 Targets

BMW's current automatic gearboxes are themselves leading products in terms of comfort, efficiency and sportiness. Nevertheless, new developments have deliberately focussed on a concept with a dual clutch. There are various reasons for this decision: The rpm capacity of the gearbox concept is decisive for applications with high-revving sport engines, because engine speeds beyond 8000 rpm (the new Dual Clutch Transmission is designed for 9000 rpm) are beyond the capabilities of conventional planetary automatic gearboxes with torque converters. A dual clutch transmission (DCT) offers significant efficiency benefits compared to current automatic gearboxes and enables significant consumption advantages to be achieved.

A dual clutch gearbox offers the possibility of using the gearbox both in comfort-oriented cars as well as in high-performance sport cars without notable modifications, because the concept has been designed for great flexibility and therefore adaptability to various applications.

Given the objective of combining this adaptability with ambitious efficiency requirements, development work for the new gearbox focussed on how to resolve this apparent conflict of interests, and to achieve the following specific properties:

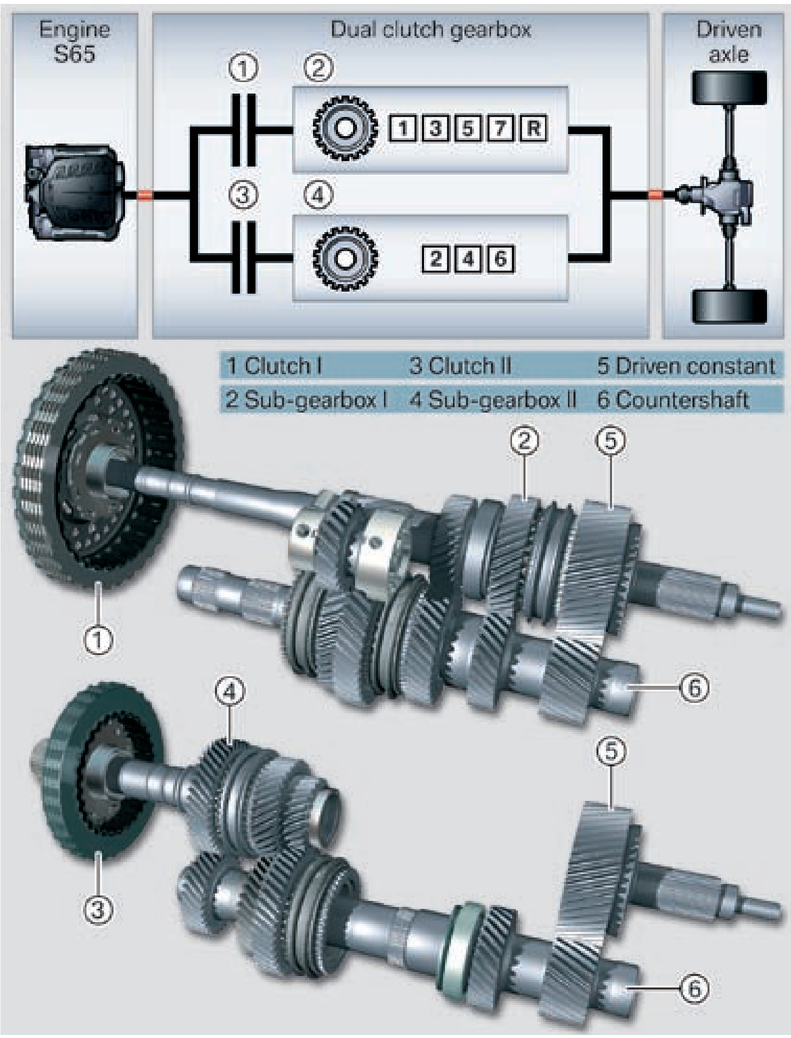

Figure 1: Gear set

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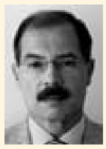
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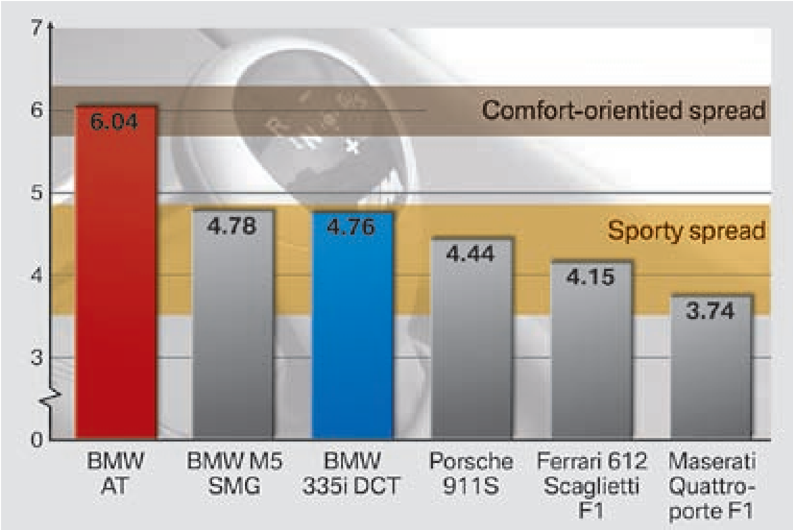

Figure 2: Comparison between gearbox spreads in competing products

- package compatible with the BMW planetary automatic gearbox with converter at torques up to 600 Nm with a comparable system weight
- suitability for high-revving engines
- high efficiency with consumption benefits compared to current automatic transmissions (AT)
- dynamics with high driving performance due to a sporty spread and closely spaced gears
- driving comfort at least at the level of an automatic gearbox; the gearbox should be capable of replacing previously offered automatic gearboxes
- straightforward adaptability of the gearbox to various car applications by creating flexible function software.

At this point, it should also be mentioned that the development triggered a technological arms race between DCT and AT designs, which in the final analysis will have positive effects on both technologies.

2 Working Model in Development

The concept selection and choice of Getrag as the provider also instigated a new cooperation model between original equipment manufacturer and supplier.

The cooperation between BMW and the system supplier was to be significantly more intensive and closer than normal in this project.

As a rule, the core expertise of the OEM on the development side lies in precisely defining all requirements and interfaces, achieving integration with the car and the application as well as safeguarding the component in the car environment. In this specific case, however, there was a particularly challenging target of developing the first dual clutch gearbox for standard drive which would be capable of operation at high revs and suitable for series production, and getting it ready to go into production within less than three years. To achieve this task, specialist teams for hardware, function development and software were formed from the start of development, composed of employees from the different companies, and supported by experts in development methodology. These teams were responsible for all of the development from the concept phase and system design through to the safeguarding stage.

3 Technical Features of the New Dual Clutch Gearbox

3.1 Gear Set

Right from the concept stage of the dual clutch gearbox, it was necessary to consider the objective of package neutrality with the current six-speed automatic gearbox. The required torque capacity up to 600 Nm would lead to a gearbox concept with an output constant and a vertical mechatronic unit positioned on the side. Such a gear set concept increases the rotation speeds within the gearbox to a higher level, but on the other hand it reduces the torques and the masses to

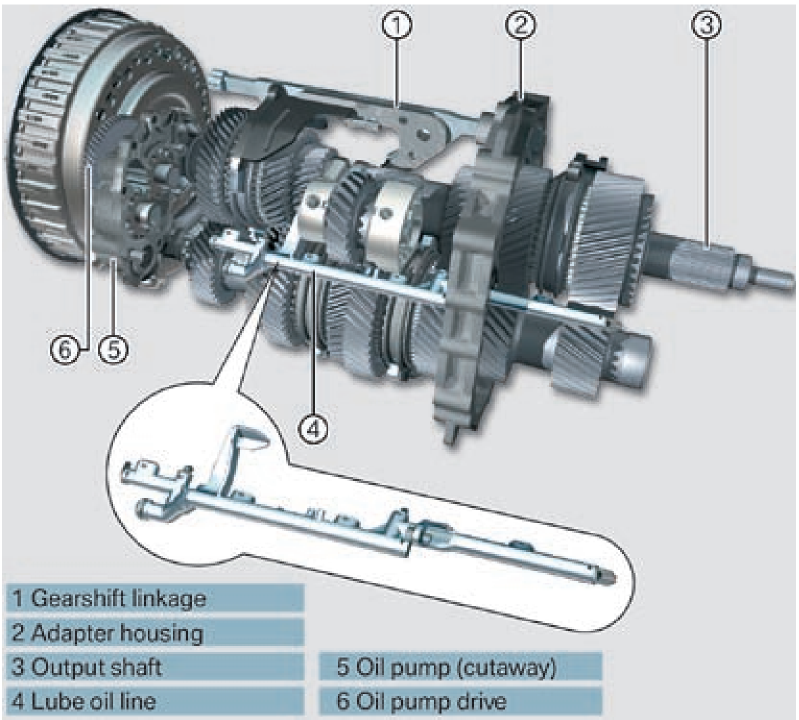

Figure 3: Lubricating oil concept

be synchronised, permitting smaller dimensions and making it possible to stay within the specified package and weight targets. **Figure 1** shows a section through the gearbox with both sub-gearboxes and the countershaft. Sub-gearbox one contains gears one, three, five, seven and R, while gears two, four and six are on sub-gearbox two.

With seven gears, sportily tight gear spacing giving a small spread of 4.8, an optimum gear ratio is available for any driving situation, **Figure 2**. In order to allow engine speeds of up to 9000 rpm, the seventh gear is designed as a direct gear in order to avoid excessive cardan shaft speeds. To maintain adequate ground clearance in spite of this gear set arrangement, the developers positioned the mechatronic systems on the side of the gearbox. This allows the driver finger from the hydraulic gearshift actuation to engage directly with the selector rods, thereby delivering a high level of integration and permitting straightforward effective actuation with very short hydraulic travels and therefore helping to achieve the demanding dynamic requirements. To meet the exacting efficiency requirements placed on a modern gearbox in spite of the increased speed level in the gear set, the engineers designed a dry sump and injection lubrication. Precisely positioned nozzles guarantee lubrication of the gearing, while the bearings are lubricated through the hollow shafts of the gear set, **Figure 3**.

3.2 Dual Clutch

The dual clutch is a conventional multi-disc clutch with a radial design and hydrodynamic pressure equalisation. The clutch is connected to the engine by means of a section with a dual mass flywheel, while the input shafts of both sub-gearboxes are each connected to the internal disc carriers. The clutch is mounted in the gearbox by a stator fixed to the housing, which also functions as a rotating conduit for the pressure and cooling or lubricating oil. Numerous design details have been integrated in order to reduce drag torque specifically. For example, the friction linings have been attached to the permanently rotating external discs on the engine end, in order to pump the oil out of the clutch as quickly as possible even when the car is stationary.

3.3 Mechatronics

The mechatronic unit is arranged on the side of the gearbox, similarly to a planetary automatic gearbox with converter and is shown in **Figure 4**. It consists of an electric module with sensors and the hydraulic/actuator unit.

3.4 Actuators, Hydraulics

As in all components, the ambitious targets in terms of efficiency can be clearly seen right from the concept stage. Oil pressure is supplied via a relatively small geared pump with parallel axes, the power of which is not designed based on the large volumetric flows that occur when starting uphill or towing a trailer, but exclusively covers the basic requirement, **Figure 5**. The size means that the power losses are guaranteed to be small. For maximum cooling, the pump is assisted by an additional sucking jet pump with jet amplification up to a factor of 2.5.

Only the main pressure valve is configured as a pilot valve, in order to achieve low system leakages at the same time as fitting the hydraulic system within a compact space. On the other hand, the pressure regulators for clutches and gearshift valves are directly controlled valves. The suction filter standard in automatic gearboxes was supplemented by a pressure filter arranged additionally in the lubricating oil path in order to maintain the required level of oil purity throughout the entire service life with only one (lifetime) oil fill.

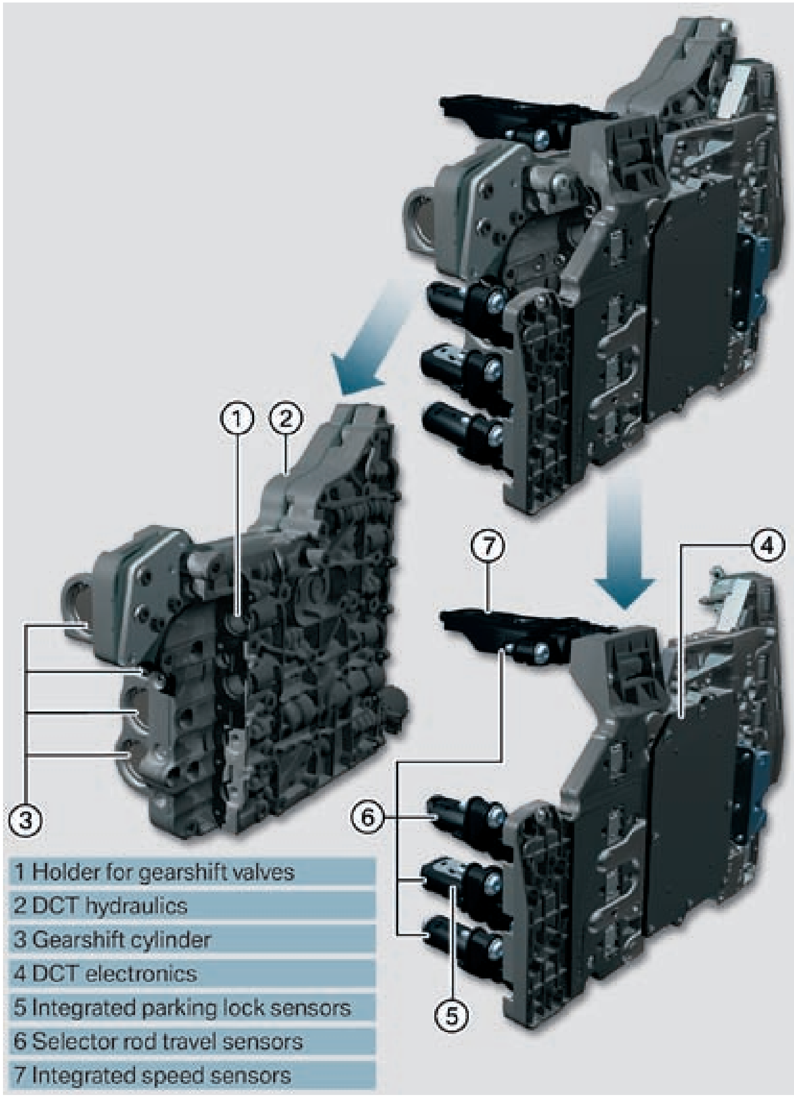

Figure 4: Mechatronic module

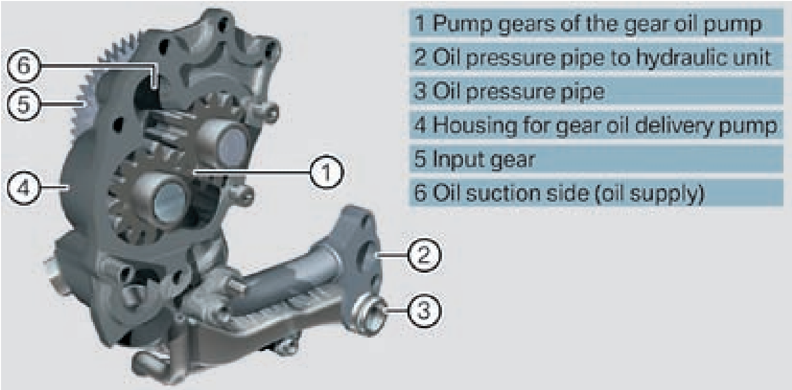

Figure 5: Gear oil pump

Achieving a lifetime oil fill is an innovation because dual clutch gearboxes have previously required oil change intervals of 60,000 km in general.

3.5 Electronic Module

With the exception of a combination sensor (input speed and clutch temperature), the electronic module integrates all sensors necessary for the system in the DCT electronic control unit.

The gearshift system is constructed with hybrid technology and contains the modern 32-bit microcontroller in the Infineon Tricore family. Its on-chip components such as Controller Area Network and Serial Periphal Interface controller, analog-to-digital converter, Input/Output channels, Random Acces and Read Only Memory make it possible to place the monitoring processor with electrical power supply as well as the output stage Application Specific Integrated Circuits and their power semiconductors in the available space.

The aluminium die cast housing for the electronic control unit is immersed in oil for cooling purposes, and carries the sensor and valve banks mounted on the side and contacted using flexible cables. A modular plug mounted directly on the valve bank provides the connection to the outer gearbox plug on the top of the gearbox and to the combination sensor by means of an internal wiring harness.

This means the electrical interface to the car's electrical system is guaranteed to be in the optimum position in terms of temperature.

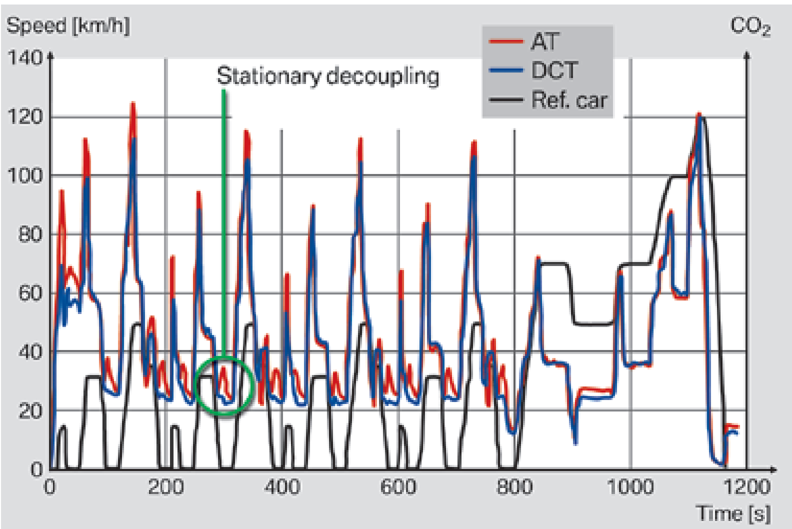

Figure 6: Overview of phase consumption: significant advantages in the stationary phases

4 Function Software Concept

It was important for the actuation of the clutches to be made subject to a strategy in order to achieve the demanded driving behaviour spectrum from comfortable to dynamic. As a result, the new gearbox installed in the new BMW 335i makes it possible to replace the previously offered automatic gearbox whilst meeting the comfort requirements of former automatic gearbox customers in all respects. In the M3, the gearbox replaces the sporty Sequential Manual Gearbox (SMG) whilst losing nothing of its dynamic properties, indeed exceeding them in part. To enable additional variants to be derived efficiently, the function software of the gearbox has been developed using a model-based approach. This means it is possible to influence the application broadly using characteristic parameters that approximate closely to the driving behaviour. The separation between gearbox and car-specific parameters allows specific adaptations to be made for new car variants without having to provide new data for the entire gearshift sequence. The strategic capability of the clutch control considered in this regard makes it possible to recreate a wide bandwidth when driving.

4.1 Intelligent Gearbox Functions for Dynamics and Efficiency

Particular attention was paid to developing internal gearbox functions such as the cooling and lubrication systems. Activation of the cooling and lubricating systems was structured strictly in terms of requirements in order to control the oil circuit and keep the pressure level in the hydraulic system as low as possible for efficiency reasons. In conjunction with the needs-based pressurisation of the gearbox actuators, the software enabled significant improvements to be achieved in gearbox efficiency as well as consumption.

It has been possible to reduce the clutch pressures during standstill phases to such an extent that only a minimum stationary lag torque remains. The gearbox therefore achieves significant consumption benefits compared to automatic gearboxes with torque converters in particular, even when using

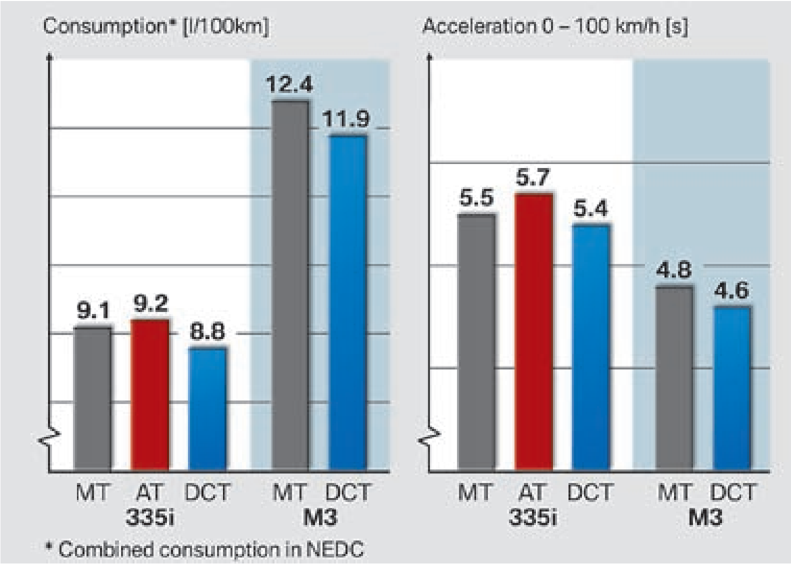

Figure 7: Performance and consumption compared to other gearbox concepts

their stationary disconnection mode, as shown in **Figure 6** based on the momentary consumption. Intensive consideration of the moving-off functions mean that the driver does not know that the driveline is completely open when stationary, because there are no noticeable sacrifices in terms of response and comfort when moving off, in spite of the standstill disconnection. In order to implement the driver's wishes with only extremely short response times, an intelligent predictive strategy was implemented for the sub-gearbox that is not in the power flow in each case. Depending on the driving situation, the function keeps the next gear ready for engagement with a high degree of accuracy, before it is requested by the driver. In this way, it is possible to save time on engaging the gear, allowing dynamic properties to be achieved immediately. In driving situations where no gear change is to be expected, the predictive function stays in the background, however, in order to avoid unnecessarily increasing the gearbox lag torque and therefore incurring disadvantages in terms of consumption.

4.2 Efficiency, Performance, Consumption

The described measures enable the dual clutch gearbox to combine efficiency and dynamics. In spite of the sportily positioned narrow spread of 4.8 with seven gears, it achieves a consumption bonus of about 5 % in the New European Driving Cycle compared to current automatic gearboxes, **Figure 7**. At the same time, the DCT scores significant performance improvements compared to the same basis, for example accelerating from 0 km/h to 100 km/h is 0.3 s faster.

5 Characteristics of Driving Properties and Car Application

The concept described and the flexible, modular function software allows the driving properties of cars equipped with dual clutch gearboxes to be offered in a reproducible way across the entire bandwidth between dynamic and comfortable. **Figure 8** shows the possible applications for the gearbox compared to previous gearbox concepts. The strategic capability of the clutch control system and therefore the option of forming different drive programmes makes it possible to set the entire bandwidth from comfortable to dynamic in one and the same vehicle, with any degree of subdivision.

The significant differentiating capability is clearly shown in the different embodiments of the gearbox in the new BMW 335i with DCT and the new M3 with M-DCT and Drivelogic. In the 335i, the DCT replaces the planetary automatic gearbox with converter used previously, and is therefore adapted for comfort. At the same time, it offers the customer dynamics. The M3 is definitely positioned in the sporty segment. In addition, it offers advantages in terms of driving comfort compared to the previous SMG gearbox. As well as driving properties, the gearbox offers additional possibilities for providing further functions depending on the application of the car. This means differentiations between cars are simple to achieve in spite of them having the same gearbox hardware. The way in which these freedoms are used becomes particularly apparent in the following examples: freely applicable moving-off behaviour, launch control, slip recognition and the flexible operating concept with differentiation in driving behaviour.

5.1 Different Moving-Off Behaviour

The moving-off clutch makes it possible to apply the moving-off behaviour as required. The 335i creeps forward when

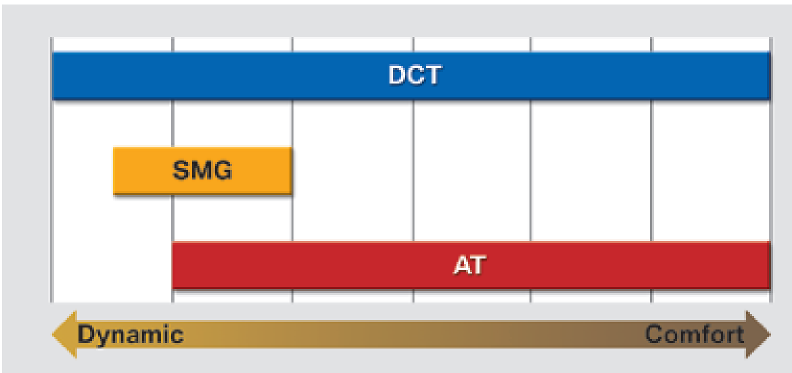

Figure 8: Extent of the driving properties that can be represented with different gearbox concepts

Figure 9: Obtain pictures of both selector levers

the brake is released, similarly to with a planetary automatic gearbox with torque converter, whereas the new M3 initially remains stationary. Only when the accelerator pedal is pressed does the vehicle start moving and its speed can be precisely controlled with the brake as the car creeps forward. The amount of the particular creep torque and the transition from stationary to creep movement as well as the subsequent moving-off procedure can be designed individually and optimally by the application engineers for each car application depending on the load condition.

5.2 Launch Control

Launch Control (LC) in the new M3 offers the greatest possible car acceleration with optimum friction coefficient. Similarly to Formula 1, the clutch allows a defined amount of slip at the driven wheels. This involves evaluating all necessary information such as slip based on the differential speed between the front and rear wheels, engine torque, clutch torque, clutch position and friction coefficient. If the drive force of the rear wheels exceeds a maximum longitudinal force that can be transmitted, due to surplus engine power, the clutch is moved towards the "open" direction. The clutch is moved back in the "close" direction if the rear wheels then drop bellow an empirically determined differential speed threshold. The engine outputs its maximum rated power continuously. This interplay permits reproducible driving performance which cannot be achieved with a manual gearbox, even by professional racing drivers.

5.3 Slip Detection

The slip detection Stability Clutch Control (SCC) specific to the BMW M allows the gearbox to stabilise the car when there is a high engine drag torque on the gear axle (negative slip). The particular clutch is opened and closed under control depending on the dynamic driving situation. Numerous sensor measuring parameters are applied to a model and considered by various weighting factors. In addition, the friction coefficient of the carriageway is evaluated. If necessary, the clutch is opened according to the gradient, the engine speed is set to just bellow the target speed for the gear and the clutch is closed with a ramp profile in accordance with the driving requirements. This means lateral stability during coasting is also guaranteed by the DTC when the Dynamic Stability Control (DSC) is inactive.

5.4 Operating Concept

The operating concept also reveals clear differences between the characteristics of the gearbox at BMW and M as far as the customer is concerned. The 335i uses an R-N-D based operating concept like in the current automatic gearboxes, thereby providing the familiar operating logic to previous automatic customers, whereas the new M3 has the joystick concept familiar from SMG gearboxes, **Figure 9**. The various configurations mean that the customer is able to select between a different number of drive programmes depending on what the car is used for, as shown in the **Table**. This flexibility is used in particular in the BMW M-specific Drivelogic: To offer the M customer individual adaptation options for the gearshift characteristics of the gearbox, the proven operating concept of the SMG was used as the basis for M DCT Drivelogic. The eleven logical drive programmes (six in sequential mode, five in automated mode) leave the driver the opportunity to adapt the gearshift characteristics individually according to his/her driving style. This means a logical drive programme is stored for each driving style. In D mode, this means that the range is designed from comfort-oriented programmes through to the sport programme. As a result, drive programme D1 moves off in second gear when carriageway friction coefficient is low, and the selection of shift points is set according to specific favourable engine load statuses. This property minimises fuel consumption of the M3, amongst other advantages. Drivelogic D5 has a completely different character. This has been specifically configured for dynamic driving, and detects racing track use, for example, by means of the extensive

	M3	335i
Operating concept	Joystick, absolute gearshift pattern	Joystick, relative gearshift pattern
Shift paddles	Plus/minus paddles	Selector rockers
No. of drive programmes	11	6
Moving-off behaviour	Moving-off assistant	Creep
Racing start	Clutch control	DSC control
Kickdown downshifts in manual mode	no	yes
Mandatory upshifts in manual mode	no	yes
Wheel breakaway detection	yes	no
Shift lights	yes	no

Table: Characteristics of the DCG in the BMW M3 and BMW 335i

battery of sensors so that the correct gear selection can be specified.

The philosophy based on S mode is very closely oriented to that of the manual gearbox. Basically, gearshift dynamics increase the higher the engine speed, load and selected drive programme. The comfortable drive programmes are adapted from comfortable/dynamic S1 through to the sporty gearshift in S5. S6 can be selected with DSC inactive as a sport-based drive programme for purists. Excess torques at the clutch make it possible to increase driving dynamics further by means of a palpable, positive acceleration thrust.

In the 335i, the driver can choose between comfort-oriented D mode and dynamic-oriented S mode, both with logically optimum gear selection. If a driver prefers to select the gears personally, this option is available in M mode which can either be selected permanently using the selector lever or temporarily (temporary manual) by operating the steering wheel paddles in D mode. By operating the additional sport button, the driver can give the individual drive programmes an even sportier mode. Even in the new BMW 335i, the gearshifts in sport mode are significantly more dynamic than those in comfort-oriented D mode. However, the range of gearshift characteristics is not quite as wide as in the new M3, in response to the particular customer target group. The sporty talents of the gearbox and possible additional functions are also displayed by the BMW M-specific shift lights.

The philosophy of upshift indicators as used in Formula 1 cockpits has been taken to its next logical step with shift lights. They permit optimum car acceleration with maximum use of engine power, because the loss of acceleration by inadvertently driving in the speed limiter range is prevented. Eight Light-Emitting Diodes (LED) units inlaid in the top area of the decorative ring around the rev counter indicate the upshift point. First of all, the approach to maximum engine speed is signalled by six LED elements that light up yellow, and the gearshift should be performed at the latest when two LED units are lit red.

6 Summary

BMW is presenting efficient dynamics with the new dual clutch gearbox. The Getrag gearbox with the comfort properties of a planetary automatic gearbox with converter exceeds this in terms of performance and consumption thanks to consistent optimisation of the gearbox design and concept. By designing the function software accordingly, it is possible to represent the entire driving behaviour spectrum from dynamic through to comfortable. With the help of the configurable operating concept, drivers of the new dual clutch gearbox will be capable of selecting their required driving properties in one and the same car. ■

Consideration of the Resonance Effects in the Fatigue Analysis of the Body in White

In the development of the body in white (BIW) the fatigue evaluation is an important building block in ensuring the functional characteristics. Due to the continuously increasing time and cost pressure in vehicle development, a reliable fatigue evaluation based on digital methods is absolutely essential. Yet the current methods cannot sufficiently consider the dynamic effects which are induced by the natural vibrations. Components with concentrated masses are mostly affected by this shortcoming. Hence, proper dimensioning of the connections of these components based on digital methods involves considerable risks at present. In order to fill this gap, a calculation method has been developed by Mercedes-Benz and the Fraunhofer Institute LBF, which takes the dynamic effects into account via superposition of the modal stresses. The procedure will be presented in this article using the example of a motor pump unit.

1 Introduction

In the development of the car bodies, the necessity to reduce the time and costs of the development is growing continuously. The fatigue tests comprise a significant cost factor in the development due to their complexity and the required time. Therefore, a reliable fatigue evaluation during the digital product development offers a high potential in terms of saving time and costs. For this reason, in the Mercedes-Benz-Cars Development computer based simulations of the full vehicle durability tests are performed by means of a combination of finite element analysis (FEA), multibody simulation (MBS) and fatigue life analysis.

With the implementation of the computational fatigue life estimation instead of the stress-based evaluation using static load cases, a significant improvement in the reliability of the CAE analysis was achieved. Consequently a substantial increase in the maturity of the tested prototypes was obtained. For the experimental durability validation of the BIW, full vehicle tests on test rigs are carried out. In addition, supplementary fatigue tests with sub-assemblies are conducted, among which many vibration table tests are found. These are more favorable both in terms of costs and complexity compared to the full vehicle tests. Especially for the mounted parts, which often cause fatigue problems due to the resonance effects, vibration table fatigue tests are conducted with the corresponding sub-assemblies of the BIW.

With the increasing demands on the automotive industry regarding, among others, exhaust gas emissions and fuel consumption, new components are being introduced into vehicles in development, such as the AdBlue tank, HV batteries of the hybrid vehicles, or the motor pump unit for the electrically powered hydraulic steering.

One typical characteristic of such components is that they compose high concentrated masses. In the areas where they are connected with the BIW they may have very low natural frequencies, which lie within the spectrum of the design-relevant test track excitations. Fatigue issues within these areas cannot be sufficiently identified using fatigue life analysis with quasi-static superposition. No relative assessments can be made, and hence it cannot be evaluated, whether design changes are effective or not. So far this problem has to be dealt with using an increased scope of testing. In addition to the full vehicle fatigue tests, vibration table tests are conducted on subassemblies of the BIW in order to guarantee the fatigue strength of the BIW in these areas. Using the new analysis method presented in this article it is possible to simulate these vibration table fatigue tests with consideration of resonance effects. This is realized by the representation of the natural vibrations of the structure according to their participation in the load spectrum, by means of the so-called modal superposition method.

2 Procedure of the Fatigue Life Analysis of the BIW

The procedure of the method, which is currently used in the Mercedes-Benz Cars Development for the fatigue life analysis of the BIW, is schematically illustrated in **Figure 1**. With the help of the virtual test rig (multibody simulation) the load time histories acting on the BIW are calculated based on the measured wheel loads [1]. The stresses in the BIW are calculated for unit loads acting on all suspension and drivetrain attachment points using finite element analysis, by applying each force individually on the body under quasi-static conditions. Here in the equation of motion the inertia force, which originates from the accelerations of small elastic deformations, is neglected due to the approximations of the so-called inertia relief method (Eq.). On the ba-

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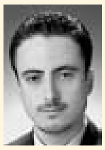

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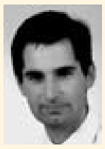

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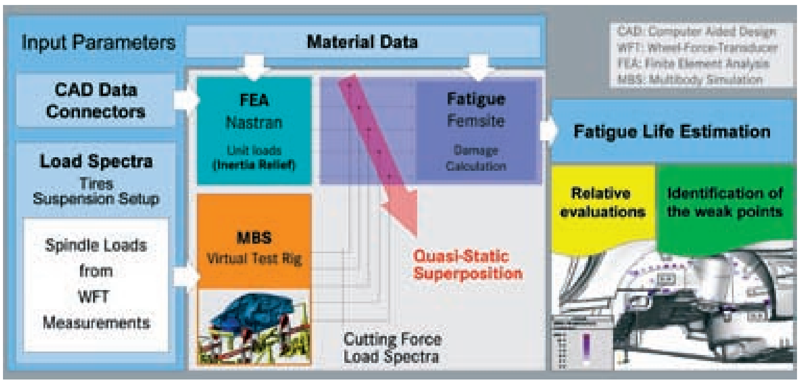

Figure 1: Flowchart of the fatigue life analysis of the BIW

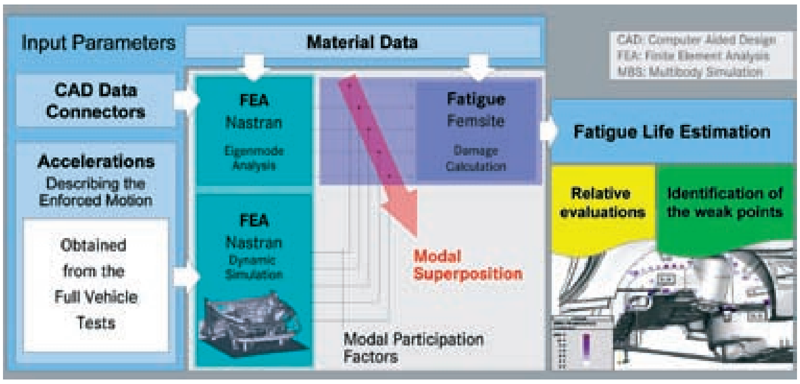

Figure 2: Flowchart of the fatigue life analysis with modal superposition using dynamic FE vibration table simulation

sis of the cutting force load spectra, the individual stresses (obtained by FEA) are scaled and superposed (quasi-static superposition) in the fatigue life analysis software FEMSITE [2] and the stress-time histories for each element of the BIW finite element model are generated.

$$\underbrace{[m]\ddot{\vec{\Delta}}}_{\approx 0} + [k]\vec{\Delta} = -[\tilde{m}]\{a_{sp} + \dot{\vec{\omega}} \times \vec{r} + \vec{\omega} \times (\vec{\omega} \times \vec{r})\} + \vec{F} \qquad \text{(Eq.)}$$

These stress-time histories are evaluated in the following fatigue life analysis using the critical plane approach and Neuber method. Damage parameter – fatigue life curves (P_{SWT}-N) based on strain controlled S-N curves define the limits of the local strain. Fatigue life estimation is carried out by calculating the cumulative fatigue damage according to the relative Palmgren-Miner rule [2]. An evaluation of the fatigue life of the BIW can be performed with the results of the analysis. The weak points can be identified and relative evaluations can be made.

In practical applications the results of this method have a high accuracy, as long as no resonance effects occur in the examined structure. However, the reliability of the method is limited in those areas of the BIW in which resonance effects arise due to low natural frequencies lying within the excitation spectrum [3]. The reason for this is the approximation made in the inertia relief method, which is used in the calculation of the stresses in the BIW. The neglected inertia force from the accelerations of small elastic deformations is not trivial if the acting forces excite a structural eigenmode. Thus, in the subsequent quasi-static superposition the information about the dynamic effects is lost.

3 Fatigue Life Analysis with Modal Superposition using Dynamic FE Vibration Table Simulation

The procedure of the fatigue life analysis with modal superposition via dynamic finite element (FE) vibration table simulation is schematically illustrated in **Figure 2**.

First an FE model of a sub-assembly of the BIW which corresponds with the subassembly of the vibration table fatigue tests (including the supporting plates and frames) is built. A dynamic vibration table simulation is performed by exerting the accelerations, obtained from the full vehicle tests, on the vibration table sub-assembly as enforced motion using a modal transient FE analysis. In the FE analyses the displacements and the corresponding stresses in each mode of the structure, as well as the participation factors of each mode at each time step of the vibration table simulation are determined. The stresses in each mode are scaled and superposed with the corresponding modal participation factors and the stress-time histories for each Element of the FE model are obtained, using which afterwards a fatigue life analysis is carried out.

The difference of this approach from the standard fatigue life analysis method is that in this case no quasi-static superposition but instead a so-called „modal superposition“ is carried out, in which the dynamic effects due to resonances are also taken into consideration. In the modal superposition instead of the cutting force load spectra the modal participation factors are used. Accordingly instead of the quasi-statically calculated stresses of unit loads, the stresses in each eigenmode of the structure are employed. After the determination of the stress-time histories, the same damage

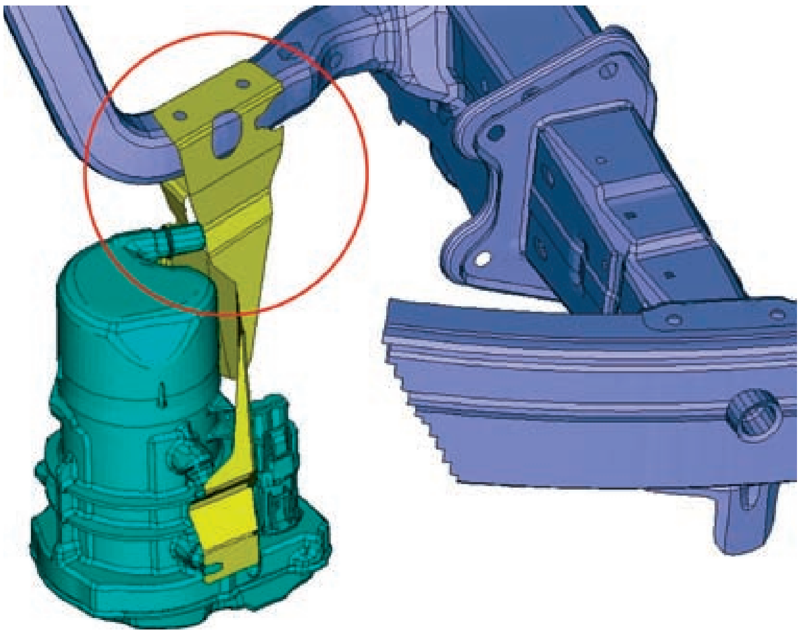

Figure 3: Motor pump unit of the electrically powered hydraulic steering system

calculation as used in the quasi-static approach is conducted, namely the comparison of the loading with the loadability using the principle of linear damage accumulation according to Palmgren-Miner modified.

Fatigue life analysis with modal superposition was investigated in several studies in the past few years [4, 5, 6, 7]. The common approach in these studies is to determine the modal participation factors by means of a multibody simulation, whereas the modal stresses are calculated in an FE analysis. The procedure presented in this article does not require multibody simulation. Only FE and fatigue life analysis methods are used, which simplifies the complete process significantly. Since the fatigue life analysis is conducted with the same model of the FE analysis, it is not necessary to build a multibody simulation model. Similarly the interfaces with the multibody simulation are also eliminated.

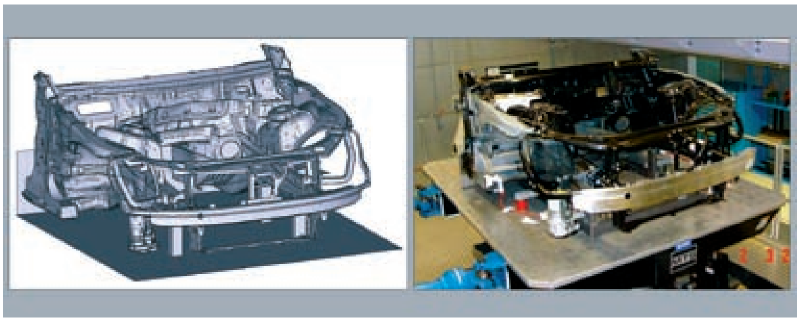

Figure 4: FE model of the vibration table simulation (a) corresponding with the sub-assembly of the vibration table fatigue test (b)

4 Example of Application from the Vehicle Development

The fatigue life analysis method with modal superposition using dynamic FE vibration table simulation was used in the simulation of a vibration table fatigue tests conducted on a vehicle front end. The focus of this investigation was on the motor pump unit of an electrically powered hydraulic steering system, Figure 3. Having a weight of about 7 kg, it was mounted on the vehicle front end in a relatively unfavorable manner due to installation space problems. A preliminary investigation indicated very low natural frequencies of the assembly of the unit together with its mounting bracket, which lie in the range of the design-relevant test track excitation frequencies. With the help of the fatigue life analysis with modal superposition, the mounting bracket of the motor pump unit was optimized in terms of structural durability.

From the FE model of the complete BIW a sub-assembly was cut out, corresponding with the sub-assembly of the vibration table fatigue test. The supporting plates and frames, which were welded to the test sub-assembly, and the vibration table plate were modeled in order to have a realistic load transmission on the structure, Figure 4. The material data as well as the connectors in the structure were used analogously with the standard fatigue life analysis method.

The natural frequencies of the structure were computed by means of a normal modes analysis, determining both the mode shapes and the corresponding stresses in the structure. The accelerations used in the vibration table fatigue test were used in a transient response analysis as input parameters for the enforced motion, to simulate the motion of the structure. Here the modal participation factors for the superposition of the modal stresses were determined. Using these input parameters the fatigue life analysis was carried out subsequently.

5 Comparison of the Simulation Results with the Test Results

During the vibration table fatigue test a crack was initiated in the mounting bracket of the motor pump unit, Figure 5 (a). Using the fatigue life analysis with quasi-static superposition it was not pos-

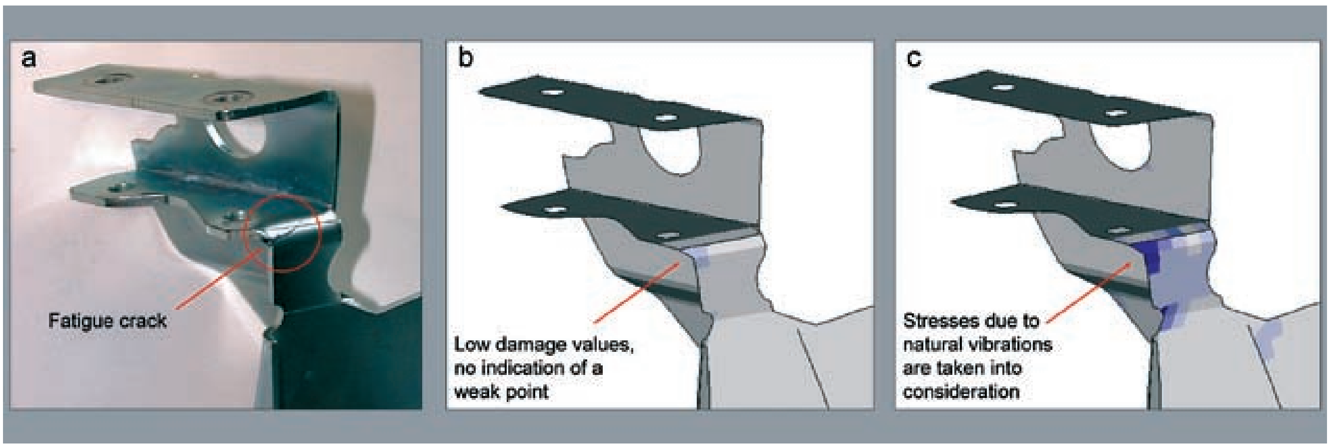

Figure 5: a) Fatigue crack in the mounting bracket; b) Results of the fatigue life analysis with quasi-static superposition; c) Results of the fatigue life analysis with modal superposition using dynamic FE vibration table simulation

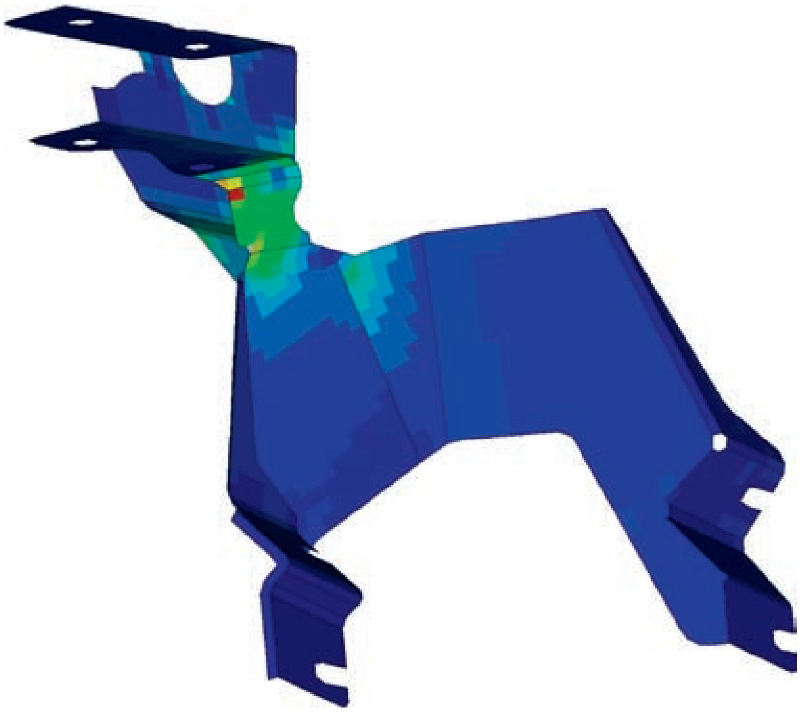

Figure 6: Results of the eigenmode analysis: Stress distribution in the mounting bracket at the lowest natural frequency of the structure

sible to identify this weak point, Figure 5 (b). With the help of the fatigue life analysis with modal superposition the fatigue failure of the mounting bracket was correctly predicted, Figure 5 (c).

The fatigue life analysis can be supplemented by an investigation of the eigenmodes of the structure. The stress distribution in the mounting bracket at the lowest natural frequency of the structure indicates that the location of the crack is highly stressed due to the excitation of this eigenmode, i.e. due to the resonance effects, **Figure 6**. If the lowest natural frequency of a structure lies within the excitation spectrum showing elevated stresses at a weak point, there is a high risk of fatigue failure of the structure. However the effectiveness of design modifications cannot be assessed by the analysis of the eigenmodes, as there is no relationship between the calculated damage value and the natural frequency, as long as the latter lies within the excitation spectrum.

By the application of the fatigue life analysis with modal superposition the risk of fatigue failure due to natural vibrations is also included in the calculated damage value. Thus, design changes can be implemented in the FE models and comparatively evaluated. Unlike the quasi-static approach, in which a comparison of design alternatives is not possible, here a number of different designs can be evaluated with respect to their structural durability. Hence, a choice can be made between different designs with consideration of the durability characteristics.

6 Conclusions

Resonance effects in the structure are not considered using the fatigue life analysis with quasi-static superposition. In the BIW fatigue problems occur, among others, in the areas where mounted parts are connected, whose natural frequencies lie within the excitation spectrum of the design-relevant test track. So far the evaluation of different design alternatives and ensuring the structural durability of the BIW in these areas was only possible through testing. By means of the analysis method presented in this article, the fatigue life analysis with modal superposition using dynamic FE vibration table simulation, it is now possible to consider the resonance effects in the fatigue life analysis of the BIW.

The method has proved successful showing a very good correlation with the fatigue failure which occurred during testing in the example of a motor pump unit. Using the fatigue life analysis with quasi-static superposition the location of the initiated crack cannot be identified as a weak point, since the reason of the failure is the stresses due to natural vibrations. The results show that by means of the fatigue life analysis with modal superposition the resonance effects and their influence on the critical spots can be taken into consideration.

Improvement of the fatigue life analysis by considering the resonance effects brings a considerable advance in the virtual vehicle development process and thus enables a substantial efficiency increase and cost reduction in the development of car bodies.

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Automatic Water Disposal System for Diesel Fuel Filters

Ongoing development of current diesel fuel filters, targeting lower emissions and reduced fuel consumption, leads to continuously increasing demands on fuel preparation. Today, nearly all commercial vehicles, and increasingly more passenger cars, use economical diesel engines, which require not only a high level of particle separation efficiency, but also efficient water separation. For regions with a high water content in diesel fuel, Mahle has now developed an automatic water disposal system for fuel filters, which actively contributes to a clean environment and lower-maintenance vehicles.

1 High-efficiency Water Separation

The water content of diesel fuel varies greatly, both around the world, and under local influences. Mahle fuel filter modules for countries with low-quality fuel supplies are therefore equipped with a high-efficiency water separation system that effectively protects our customers' injection systems from damaging effects such as corrosion, cavitation, reduced lubricity, and microbial growth. As shown in **Figure 1**, for example, the USA, Brazil, and China, as well as eastern European countries such as Russia, Bulgaria, and Romania are typical countries with low-quality fuel supplies. Diesel fuel in these regions has up to fifteen times the pollutant particle content and up to one hundred times the water content of that in Western Europe.

2 Motivation

Reliable water separation in the fuel filter module, however, is just the first step. Considering that the water content in some regions is one hundred times that of western Europe, the question naturally arises, how this immense quantity of water should be removed. In some regions with elevated water content in diesel fuel, the water reservoir in the fuel filter is still large enough to contain the water for a typical maintenance interval. In other regions, however, it is necessary to collect the water in the fuel filter module, in order to be able to manually empty it into the environment on a regular basis. This is required because wherever more water is separated, more water must, of course, be removed.

In addition to the obvious increase in maintenance with manual water disposal, other aspects usually cause difficulties as well. For passenger cars, the fuel filter module is often located, for technical reasons, in a position that is difficult to reach. In this case, a service station visit is required. Manual water disposal is even more complicated for commercial vehicles, if the water separation is implemented on an engine side fuel filter module. For these vehicles, especially, the serviceability of the automatic water disposal system is highlighted. Problems such as inconvenient installation locations, and the fact that the separated water must often be drained every day by the driver, will soon be things of the past.

3 Requirements for the Water Disposal System

Before the separated water is allowed to be automatically discharged into the environment, it must meet service water quality due to legal regulations. Some customers even require drinking water quality. Therefore, a maximum permissi-

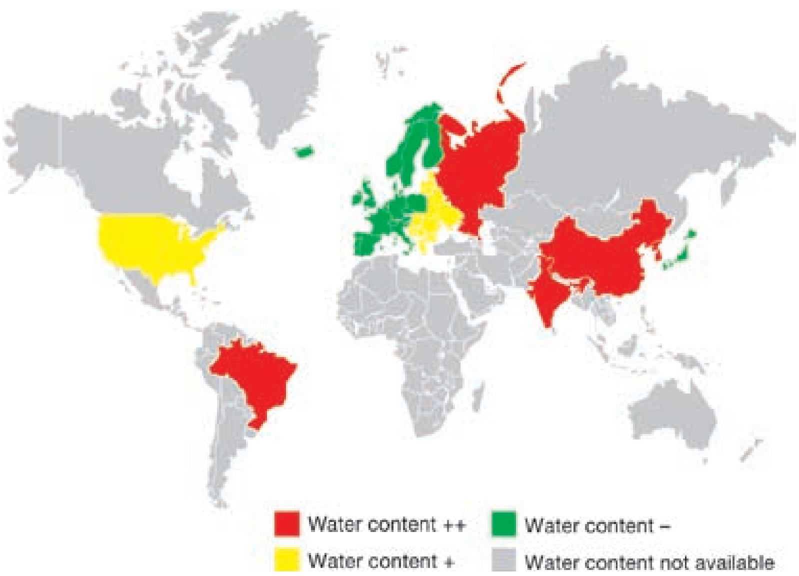

Figure 1: Global overview of water content in diesel fuel

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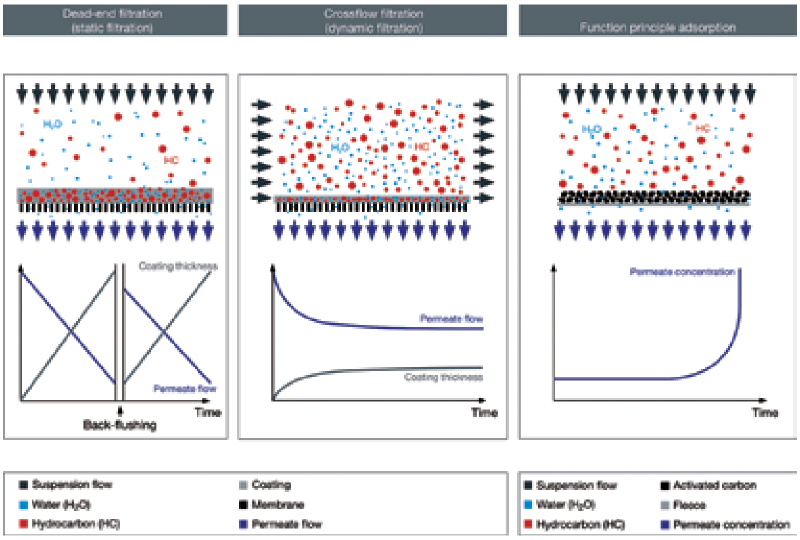

Figure 2: Comparison of diaphragm and activated carbon

ble remaining hydrocarbon content (HC) of 2 ppm (2 mg HC per l of water) is required. This ensures that future standards will also be met. This is achieved by a water purification unit, patented by Mahle, based on activated carbon, which reliably cleans the separated water, in order to prevent environmental pollution from automatic water disposal.

4 Solution Idea

Cleaning with activated carbon is a proven, state-of-the-art technology for many cleaning applications. The actual principles of effect were discovered a long time ago, and activated carbon has had a rich history ever since. Even the ancient Greeks described the use of activated carbon (wood based) to alleviate the effects of food poisoning. In Columbus' time, mariners blackened the interior of water casks with fire, because they knew that water stayed fresh longer that way.

Today, activated carbon is used in a wide range of applications. For example, it is used in gas masks, and for water purification in case of catastrophe. This cleaning effect, which is due to the adsorptive effect of activated carbon, can also be used to bond residual hydrocarbons in water separated from diesel fuel. Initial tests quickly showed the excellent adsorptive capability of activated carbon even for highly emulsified fuel contents.

5 Comparison of Various Functional Principles

Other processes can be considered, of course, for cleaning diesel-contaminated water, such as diaphragm processing. Artificial diaphragms for separation are made of polymers or ceramics that are manufactured chiefly by casting thin films. Examples include polyether sulfone, polyacrylic nitrile, cellulose acetate, or thin layers of silicone on a polymer carrier. The actual separation process is based on transport through pores (sieve mechanism, filtration, and ultrafiltration), differences in solubility, and diffusion and differential charges. The driving forces for transport are differences in pressure (filtration), chemical potential, concentration (dialysis), temperature, or charge. **Figure 2** shows the main functional principles.

Fundamentally, the use of a diaphragm for the application described above appears to be suitable, and a comparison between this technology and adsorption with activated carbon suggests itself, **Table**. As can be seen in the Table, there are significant advantages to the use of activated carbon. For example, the pores gradually clog over the service life of the diaphragm. The greatest advantage of activated carbon as compared to the diaphragm, however, is the low-cost design of the cleaning unit.

6 Functionality of Activated Carbon

In general, the condition of the surface is the main criterion for adsorption. In the case of activated carbon, however, only the size of the surface is what drives such an effective result. The huge surface "activates" the carbon, so to speak. The surface content of activated carbon is impressive, at 500 to 1500 m^2/g. One spoonful of activated carbon has more than the area of a soccer field. For special ap-

Table: Advantages and disadvantages of diaphragm and activated carbon

		Diaphragm		HC adsorber with activated carbon
Service life function	–	Clogging of diaphragm pores	+	Adsorption over service life
Media/fuel resistance	◦	Low multiresistance	+	Multiresistance
Cleaning function	◦	HC content < 2 ppm	◦	HC content < 2 ppm
System requirements	–	Required pressure	+	Suitable for pressure and suction side applications
Heat resistance	◦	Freezing water can destroy the diaphragm	+	Functional tests at t < 0 °C successful
Biological compatibility	◦	The pores can become clogged with microbiological growth	+	Optimized activated carbon to prevent microbiological growth
Complexity and system costs	◦	Water / pressure sensor and safety valve required	◦	Water sensor and safety valves required

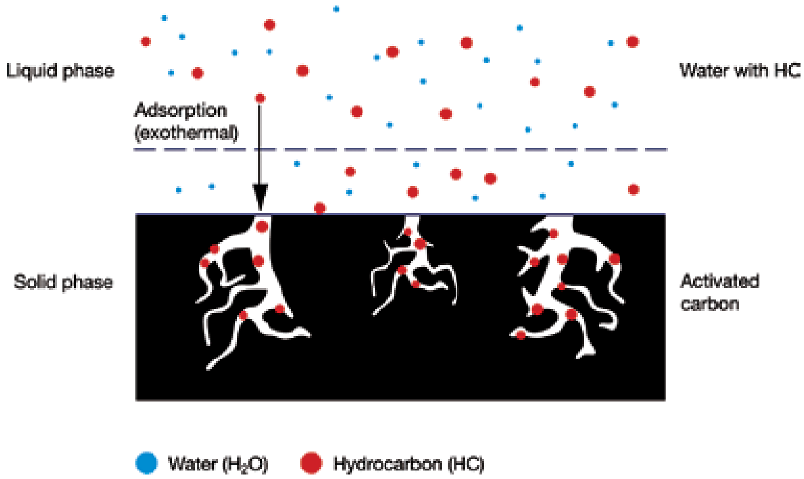

Figure 3: Functionality of activated carbon

plications, there is also activated carbon that has even greater surface content.

The enormously porous structure of activated carbon is responsible for the elimination of undesirable and contaminative substances from all liquid and gaseous flows. This consists of a carbonaceous matrix.

Physical adsorption (physiosorption) of a material on a surface is similar to a chemical equilibrium reaction. The adsorbed material (adsorbate), however, does not form a chemical bond with the surface; rather, it adheres due to larger forces similar to adhesion, **Figure 3**. Thus, as a rule, only van der Waals forces occur. Chemical bonds within an adsorbed particle remain intact, but are polarized. Finally, the hydrocarbons are bonded to the activated carbon, and the cleaned water can be discharged into the environment with no risk.

7 Design

The most important variables for the design of the system are the water content in the diesel fuel, the level of residual diesel in separated water, and the adsorption capacity of the activated carbon used.

Based on customer requirements, the cleaning element must be designed as a service life component. For a heavy commercial vehicle, that means a current service life of up to 1.6 million kilometer. Since it is not possible to tell in advance how much water will end up in the vehicle tank, and thus in the system, sensible assumptions must be made about an average expected water content in diesel fuel, and about an amount collected over the service life. The water separated in the fuel filter contains diesel components, in both dissolved and free forms (emulsion). For reliable functionality over a long service life of the automatic water separation system, a slowdown zone is helpful for separated water at a deeper location in the fuel module. The water collects there, due to its higher density, and separates from the diesel fuel. The water is disposed of ideally with flow support. An HC content of 50 to 150 ppm (mg diesel per liter water) is known from various analysis results. Mahle therefore assumes an average initial HC content of 100 ppm for the design of the HC adsorber. The maximum permissible residual hydrocarbon content, after cleaning, is 2 ppm, as described above. For the amount of water to be cleaned over the service life, a volume of about 150 ml activated carbon is currently needed.

8 Construction of the Overall System

The complete system, **Figure 4**, contains, in addition to the actual cleaning element – the HC adsorber – other main components, including a multi-level water level sensor for detecting the separated water and activation of the system,

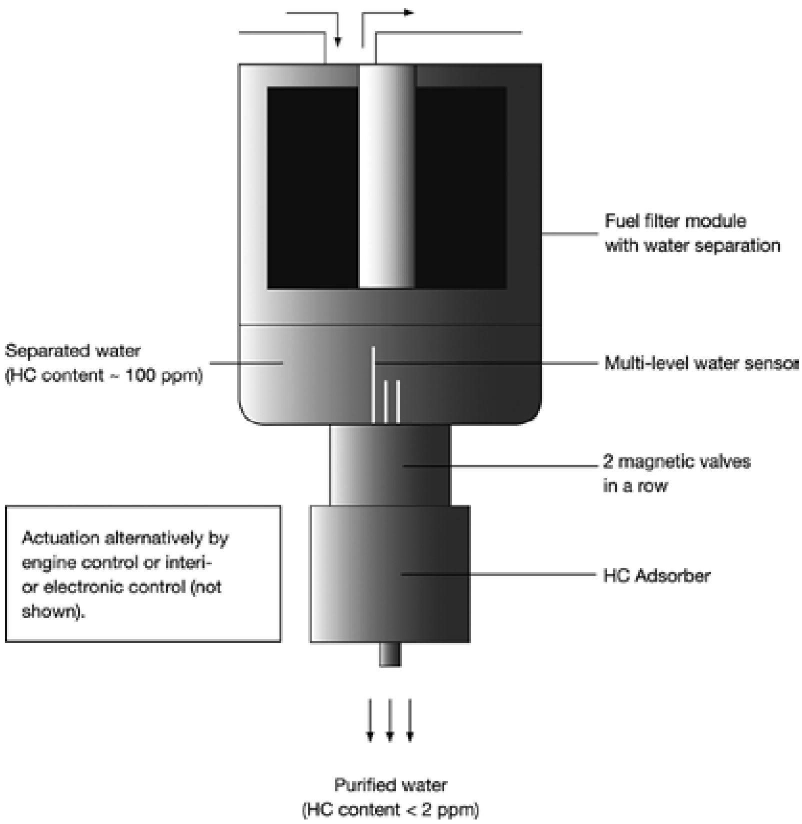

Figure 4: Principle diagram of fuel filter, with automatic water separation system, including HC adsorber

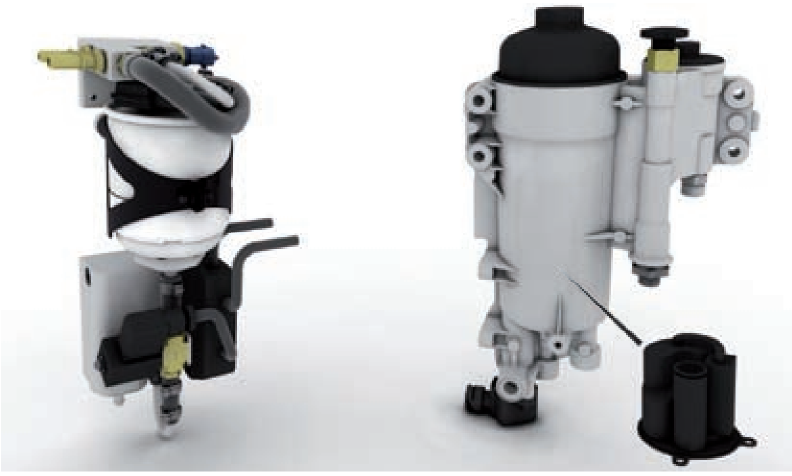

Figure 5: Adapted (left) and integrated (right) version of the automatic water disposal system

two solenoid valves connected in series, and if required, its own electronic controls. Reliable functioning of the system is ensured by a clever control and safety concept. If a certain water level has been reached, the system is activated using the electronic control unit, after validation; that means, the solenoid valves are actuated and opened for a certain time. The water then flows through both valves to the HC adsorber, is cleaned there, and can then be drained to the environment. In order to ensure that the system functions reliably under all conceivable circumstances, a multi-level water sensor is installed. If water drops below a certain second level, the system is closed immediately ("E-stop"). In addition, leak monitoring for both valves is accomplished with a third level, located even lower. The function of the valves is also checked using current monitoring. The OBD2 function has, of course, also been implemented; that means, the system reports its condition at each system start, as well as any errors as described before.

Because it is an open system, a secure closing function is fulfilled by two valves connected in series (redundancy). By accumulating the number of activations, the actual status of the capacity of the HC adsorber is monitored. Any potential premature end of service life can thus be reported to the electronic control unit, for instance, at two warning levels. In this case, more water was cleaned as was assumed for the service life, and the driver is instructed to replace the HC adsorber. For this case, naturally, it is designed as an interchangeable component.

9 Validation

In order to find the optimal activated carbon for this application, and to determine its capacity and cleaning power, a number of test runs were performed. A water-diesel emulsion was thereby generated in a standard tank, which was removed through the HC adsorber, and thus cleaned. Frequent sampling, before and after the adsorber, and analysis of the water for HC content, enabled the capacity of the carbon to be determined relative to a certain limit value. This ultimately enabled the determination of sizing, as well as service life and, consequently, a maintenance interval for the respective application of the HC adsorber.

The tests also showed that the residual diesel components in the water were reliably below the required 2 ppm. The system proved itself even at very high water disposal rates.

10 Integrated and Adapted Version

The automatic water disposal system can be implemented both as an integrated and as an adapted solution. The adapted solution has the advantage that even existing fuel filter modules can be retrofitted. Due to its flexible construction, this is mainly targeted for passenger cars and light commercial vehicles. The integrated solution, meanwhile, can be integrated very easily in the already large fuel filter modules of medium and heavy commercial vehicles. Depending on customer requirement, however, an adapted solution is possible here as well, **Figure 5**.

11 Summary

With the automatic water disposal system based on activated carbon, Mahle has been able to improve serviceability and, in this context, the environmental friendliness of future fuel filter modules. The controlled, automatic disposal of the previously cleaned water prevents environmental contamination. In addition, damage to the injection system due to the lack of manual discharge of the separated water is prevented.

A comparison to other functional principles showed that activated carbon is superior to other systems, due to both its excellent functional properties and the low cost of the overall system. Initial field tests confirm trouble-free functionality and reliability of the system. ■

The Road-Wheel Simulator

Evolution in Testing Technology

The wheel accelerated life testing rig RASS of Fraunhofer LBF in Darmstadt (Germany) is not only a new generation of test machine, but also constitutes the connecting link between the traditional biaxial wheel testing technology and future methods of laboratory simulation extended with advanced new features. The reliability of new wheel designs can be assessed on the basis of a highly realistic simulation of service loads.

1 Introduction

Modern cultural history is closely related to the invention of the wheel – that mechanical component which was instrumental in enabling the transport and exchange of goods. Yet, beyond being the enabler of a variety of industrial production and marketing processes, the wheel is also their object: Over the next five years, more than 75 million wheels will be manufactured in the European Union for passenger car production alone, 93 million in the USA and just under 30 million in Japan [1]. In Europe and Japan, around one third of all vehicles are equipped with aluminium wheels, in the USA, the proportion of aluminium wheels is even higher. This proportion also reflects the different perception of wheels either as a mass produced utility item, or as a highly individual object with a unique design, styling and colour.

The automotive industry responds to these widely different customer expectations by offering a wide range of different wheels: For the current VW Golf Comfortline 1.4 TSI, two different 16“ wheel designs are offered as options, along with a total of seven 17“ variants and a further 18” aluminium wheel. The surcharge which the end customer pays for these extras comes to between EUR 435 and EUR 1,775 – i. e. up to 8 % of the total cost of the vehicle. In this respect, the wheel serves as a distinguishing mark, which characterises the appearance of the car and contributes like no other component of a modern car towards its individuality. In another way, the wheel is also part of a continuous process of technological advance, reflecting e. g. the general increase in vehicle weights, which result in larger wheel brakes, or in the use of wheels with emergency running properties, so-called runflat- or extended-mobility tyres.

2 Loading Mechanics

In any case, the wheel/tyre system constitutes the immediate interface between the vehicle and the road surface – without any redundancy, meaning that the failure of a component will seriously threaten the safety of the vehicle, and hence life and limb of its occupants and road users. Vehicle wheels are therefore highly safety-relevant and have to meet the associated requirements regarding durability, **Figure 1**.

The loading mechanics of wheels is characterised by their movement pattern. During each wheel revolution, the component is exposed to a cyclic load, with at least one load cycle – even travelling on an even road surface without accelerating generates a distinct non steady state load and hence results in a fundamentally different behaviour from that of wheel guiding components. The load cycles associated with the wheel rotation add up to around $1.5 \cdot 10^8$ over an operating mileage of around 300,000 km and are therefore highly relevant for any kind of fatigue damage that may occur, due to the cumulated damage associated with each individual load cycle. As far as vehicle wheels are concerned, the two partial load spectra for straight-driving and cornering manoeuvres are of particular significance, **Figure 2**.

3 Wheel Testing

Testing of the entire wheel/hub system including wheel nuts, bolts and wheel bearings with simplified test methods is impossible, considering the complex interaction between the individual components. For the individual components, this means that there have been numerous attempts to reduce laboratory testing to specific attributes. For the vehicle

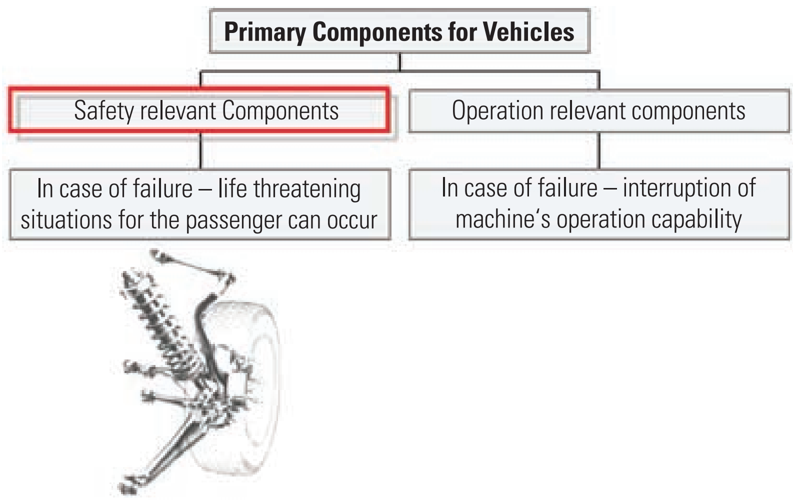

Figure 1: Wheel as safety relevant vehicle component

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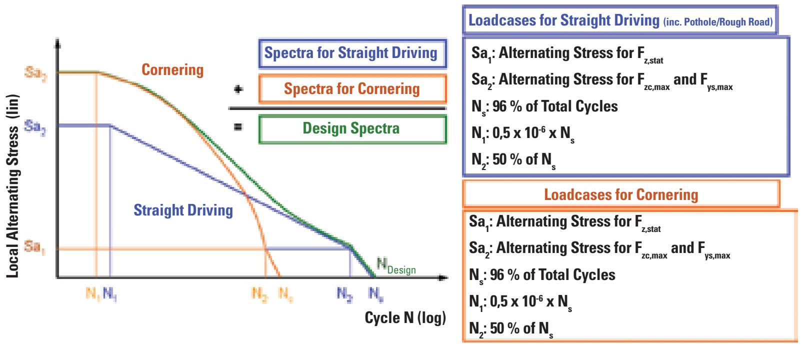

Figure 2: Operational loading of wheels and hubs

wheels, for example, cornering fatigue and radial fatigue tests have been developed, simulating typical loading situations encountered in the vehicle's service life in a highly simplified manner in the form of tests with constant loading amplitude and unidirectional action of the forces – which is really unacceptable from a durability perspective. In fact, the service loads acting on a wheel occur, within the limit loads determined by the physics of driving, in a variety of different combinations of vertical and horizontal forces and in random sequences, that means they are characterised in any case by variable amplitudes and vector addition of forces.

For reasons of time and cost, wheel testing concurrent with the tests on the entire vehicle can also be ruled out – the belated and usually limited availability of prototype vehicles and the large number of wheel design variants associated with a single vehicle model excludes this type of validation process. Likewise, the early involvement of development partners of the automotive industry such as for example the manufacturers of wheels or third-generation wheel bearings, which include some of the safety-relevant structural mechanics, calls for an extended testing method so as to enable laboratory experiments which realistically simulate actual loading conditions encountered on the road.

3.1 Bi-axial Wheel Test

In the early eighties, engineers at Fraunhofer LBF first implemented a testing system for laboratory simulation of the service loads acting on wheels and hubs [2]: The LBF ZWARP – biaxial wheel test machine was developed and built to enable vehicle designers to fully investigate the durability of rotating chassis components within a single testing system, **Figure 3**.

Unlike a tyre testing system, for example, the biaxial wheel test machine uses an internal drum to simulate the roadway. The tyre contact area this produces, and the identical curvature between the tyre and the drum ensure relatively low abrasion of the tyre and therefore reduce tyre wear. This also applies to the special fixtures for introducing lateral loads used on the test rig: Whereas on the road, side loads are generated by the action of the slip angle, the adhesion potential is limited in the case of the smooth, metallic surface of the inner drum. For this reason, side loads are introduced on the test rig with the help of lateral curb rings, which provide a force closure with the tyre side wall. With a view to achieving as realistic as possible a load input into the wheel and wheel hub – i. e. the test objects on the test rig – the effect of side load application through the lateral curb rings is compensated by changing the wheel's camber angle. [3].

In the years since 1980 the test machine developed by Fraunhofer LBF along with IST, MTS and KLOCK have been used by many vehicle and automobile manufacturers, and have proven their suitability for practical operation. Hence extensive operational experience is available from numerous applications, which has enabled the systematic further development of the concept of biaxial wheel testing. In particular, new developments in the areas of electric drive motors and open and closed loop control have permitted the development of new test rig concepts, which would have appeared impossible a few years ago. In this respect, the new test machine for wheel accelerated life testing (W/ALT) developed

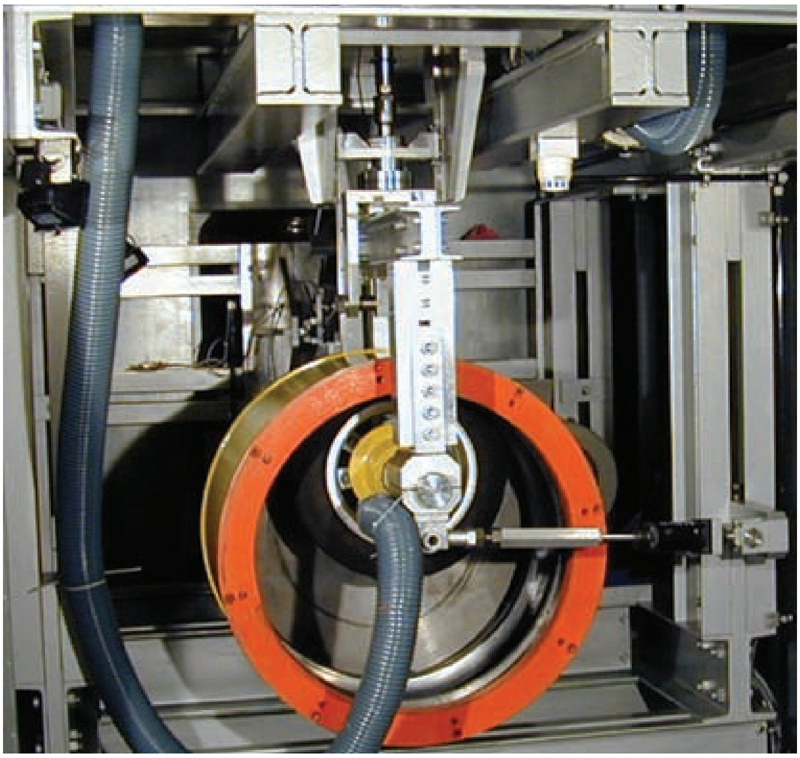

Figure 3: BiAxial wheel fatigue test machine acc. to LBF

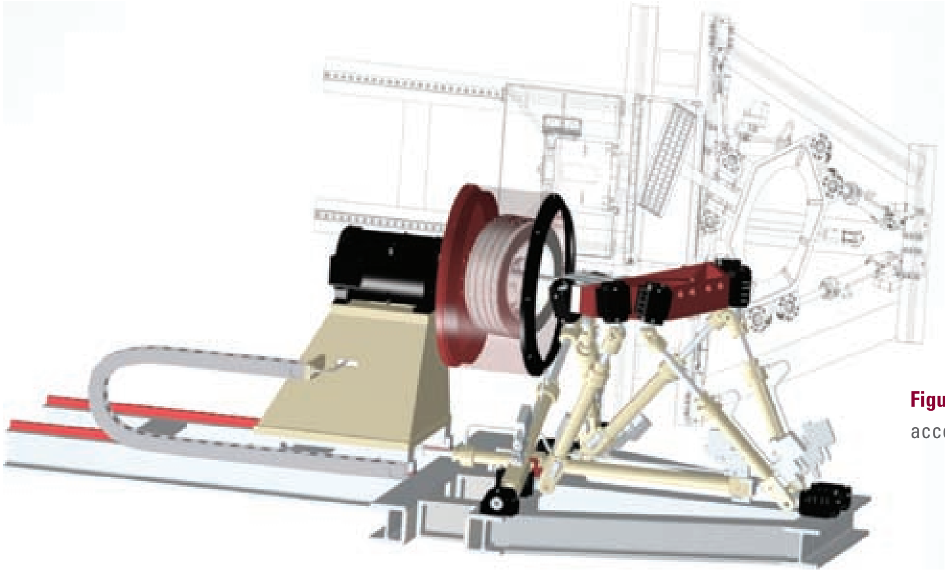

Figure 4: New LBF test machine for wheel accelerated life testing W/ALT

by researchers at Fraunhofer LBF since 2006 is the systematic further development of the fundamental principles of the biaxial wheel tests, extending conventional testing machines with up-to-date actuators and drive systems for the simulated roadway, **Figure 4**.

3.2 Parallel Kinematics

The most remarkable feature of the W/ALT test machine is the parallel-kinematics actuator arrangement, optimised specifically for this test rig. The fundamentals of this type of movement control go back to around the year 1800. At this time, the mathematician Cauchy studied the stiffness of a so-called "articulated octahedron". Around 150 years later, a similar mechanical arrangement was used by Gough in a tyre testing machine. However, parallel kinematics mechanisms did not really become popular until 1965, with the advent of flight simulators, and became known as Stewart platforms after their inventor. In contrast to traditional hexapod concepts, the operating space of the wheel within the drum has been optimised through an asymmetrical layout, **Figure 5**.

This provides maximum flexibility for testing wheels with diameters ranging from 13" to 21", along with a compact design of upper and lower hexapod platform The specific configuration of the parallel kinematics mechanism was developed and optimised in extensive numerical simulations, in close cooperation between engineers at Fraunhofer LBF and its strategic development partner, the Swiss company OHE, and included the extensive use of complex PLM functionality such as CAD, MBS and FEM.

Unlike traditional biaxial test machine concepts with limited degrees of freedom, the parallel kinematics of the W/ALT allows extremely flexible movement of wheel and hub within the drum: Apart from the application of vertical and horizontal loads to the cambered wheel, a steering angle and hence a true slip angle can be achieved.

The movement capability of the hexapod is also used to integrate a pre-damaging system located outside the drum into

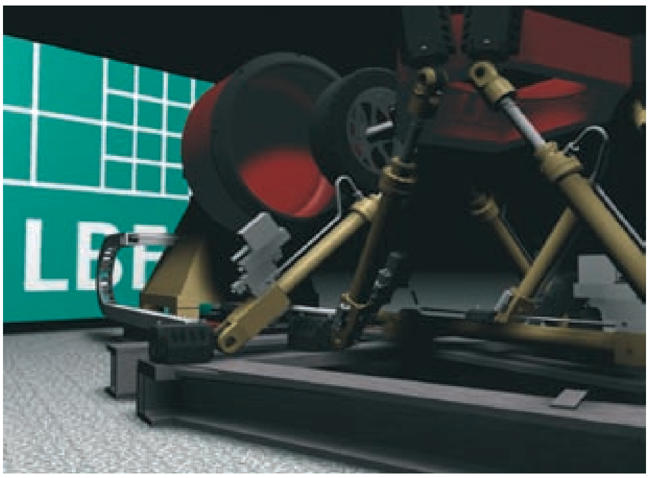

Figure 5: Asymetrical layout of parallel kinematic machine

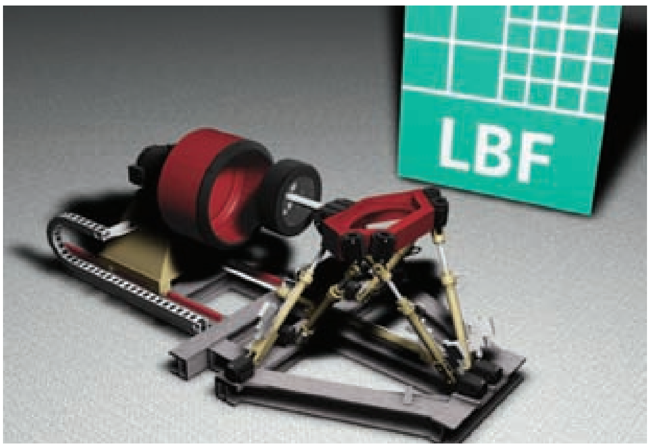

Figure 6: Overall view of LBF test machine for wheel accelerated life testing W/ALT

the overall fatigue testing concept. This system therefore enables experimental stress analysis, quasi-static introduction of preliminary damage through a load applied radially to the inner rim flange, and the fatigue test as such to be conducted with a single adjustment of the wheel.

One additional degree of freedom is used to displace the drum by a distance of 1,000 mm so as to ensure unrestricted access to the mounting position. The ergonomically favourable neutral and mounting position of the hexapod is an additional benefit for the operating staff: The wheel is mounted at a height of 1,200 mm and is therefore easily accessible for additional operations – for example the integration of the brake system.

Unlike the concept of the biaxial wheel test rig, the new system integrates circumferential forces – i. e. the test is in fact a triaxial one. This necessitates special dynamics for the drum drive. Braking torques, e. g., have only rarely been taken into account until now – which in some cases resulted in the drum coming to a complete standstill. In contrast, the wheel accelerated life testing system features an innovative direct torque motor developed specifically for this test rig – a brushless, multiphase synchronous motor with permanent magnet, capable of delivering a high torque even at low speeds. With a power output of 97 kW and a maximum drive torque of 2.2 kNm the drive system provides ideal conditions for highly dynamic testing, even when including circumferential forces.

In this way the W/ALT system provides a modular design offering distinct advantages in terms of construction, operation and maintenance. The system is due to be taken into operation at Fraunhofer LBF in the fourth quarter of 2008, **Figure 6**.

The operating space of the wheel ensured by the parallel-kinematics mechanism permits the use of all currently known loading programs for biaxial wheel testing. Noticeable compatibility problems encountered in the past, when transferring loading programs between different machine models, are overcome by the kinematic concept of the W/ALT. Regardless of load kinematic adjustment of wheel camber (LBF Type „A“), infinitely adjustable camber (IST or KLOCK Type „B“) or a coordinate system parallel to the wheel movement (MTS Typ „C“) – the test machine for accelerated life testing allows the reproduction of all machine specific movement and loading conditions. Hence the testing system provides maximum capability for running a wide range of loading programs in a testing environment which has become increasingly heterogeneous over the years. This is made possible by recreating the kinematic properties of the different test rig models, that means by the use of virtual coordinate systems at the positions of revolute and prismatic joints, and through fixed or co-rotating load application relative to the coordinate system, which allows the use of load programs using the actuators or the wheel itself as reference.

4 Conclusions

Considering the above, the wheel accelerated life testing rig is not only a new generation of test machine, but also constitutes the connecting link between the traditional biaxial wheel testing technology and future methods of laboratory simulation extended with advanced new features. With the new concept for wheel accelerated life testing the reliability of new wheel designs can be assessed on the basis of a highly realistic simulation of service loads, opening up new perspectives for durabilty research and for the productive use of the test machine in design development, validation and quality assurance for automobile and wheel manufacturers.

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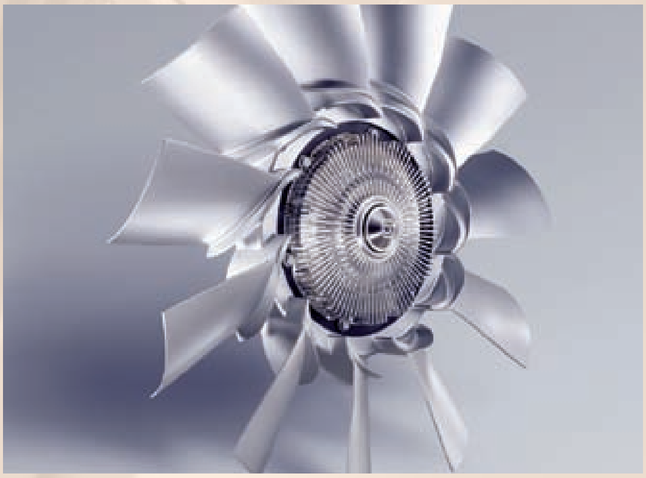
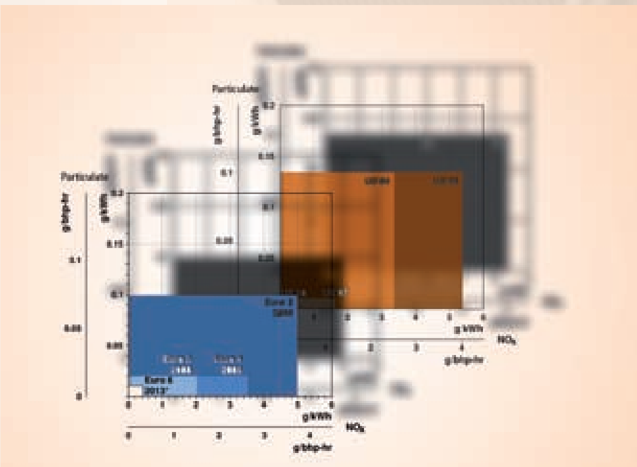
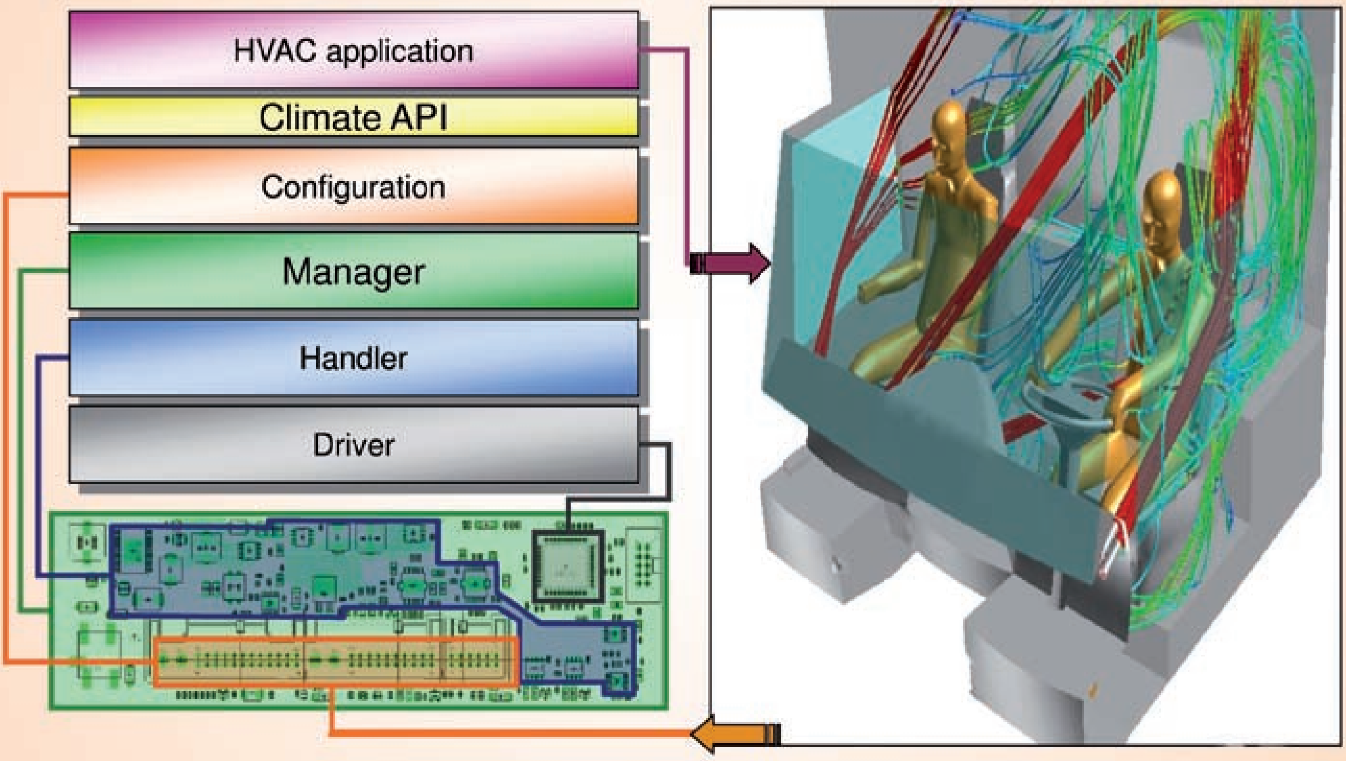
Special Behr
Thermal Management for Trucks







Ergonomics and Operating Concepts for Trucks

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort.

The Author

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1 Behr Hella Thermocontrol

Since the formation of BHTC as a 50/50 joint venture by the Behr and Hella groups in 1999, the company has grown rapidly and today is one of the world's leading manufacturers of control heads for HVAC systems. The product portfolio also includes control units (ECUs) for electric auxiliary heaters, blower controllers, and A/C sensors. The company counts the world's largest car and truck makers among its customers, and serves them not only from its parent plant in Lippstadt, but also from its subsidiary plants in North America, India, China, and, more recently, also in Japan. The BHTC mission is to provide "Comfort in Motion" by creating products that play a key role in ensuring optimum cimate comfort in cars and trucks.

2 Cars and Trucks: Differences in Climate Control

In recent years, there has been a sharp increase in comfort requirements for truck cabs. The driver's space is now recognized as a proper workplace. Ever more importance is accorded to the climate in the vehicle cab. Features that have long been standard in passenger cars have for some years now also been making their way into commercial vehicles. Today, no manufacturer can ignore its customers' demands for greater climate comfort. However, optimum climate comfort benefits not only the driver, but also all other road users as well: high interior air quality and a pleasant cab climate improve drivers' performance and help them to concentrate on the traffic.

Comfort is not only enjoying a pleasant climate in the driver's cab, but also the rapid response of the climate control system to changing climatic conditions. The system can thus ensure constantly mist-free windows and draft-free temperature control of the driver's workplace. The dash vents and the ventilation blowers are controlled in such a way that virtually no condensation forms on the windshield and side windows, and unwanted drafts are avoided.

Sensors measure the temperature at each of several points in the A/C system, and compensate for the influence of incoming solar radiation that falls directly onto the non-ventilated cabin temperature sensor. The climate control system can thus react quickly to changes.

Nevertheless, there are differences in the air conditioning of passenger cars and commercial vehicles that make the direct adoption of HVAC modules and control concepts from passenger cars impossible, Figure 1:

- A larger cab volume, and higher cabs.
- Commercial vehicles usually have a large, but vertical windshield. Compared with passenger cars, this results in less heat from solar radiation entering the cab in the middle of the day.
- Generally, the windows do not feature heat-absorbing glass comparable with that of passenger cars, and this results in a greater influx of heat when the sun is low.
- Cold outside temperatures, if they are not adequately compensated for by air conditioning, can result in an unpleasant flow of cold air at the windshield, leading to cold arms and thighs.
- Increased use as a result of ever denser traffic and frequent changes of drivers call for more user-friendly controls, that means it is important for the operator to quickly and intuitvely understand how the air conditioning system works.
- Owing to the greater movement range of the driver's seat, the operating controls must be larger and clearer in terms of their functional classification.
- The effect of the center air vent in the instrument panel is generally not so intense, owing to the greater distance to the driver.
- All system components must be designed for a longer service life.
- Today, some passenger cars have multi-zone climate control systems that must react more quickly to the changing amounts of incoming solar radiation due to the large sloping windows.
- Long-range trucks have a sleeper cab, which, in stationary operation, increasingly requires not only controllable heating, but also air conditioning; see the presentation on no-idle air conditioning.
- Passenger car platforms with high unit numbers of individual model series require specific climate control hardware and software components that are based on a standard module set. Control heads for truck air conditioning systems are also designed for platforms, but because the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software, Figure 2.

3 The New Climate Control System for the MAN TGX

For the design of the A/C control heads and ECUs for the air conditioning systems for the new MAN TGX, a modular concept was adopted from the outset. This concept makes a clear distinction between design and functionality.

The control head for the air conditioning system was thus integrated into the modern cockpit with significant space savings, and adapted to an individual design that meets demanding ergonomic and functional requirements. In all variants, mechanical Bowden cables from the control head to the HVAC system are dispensed with, and only six electric cables are used to connect the control head and ECU.

4 The HVAC Control Head

As the functionality of air conditioning systems increases, their operability often decreases. Especially in the case of commercial vehicles, owing to the long travel times with dense traffic, frequent changes of drivers, and the large movement range of the driver's seat, clearly identifiable and understandable controls are important.

We already provided an in-depth report on the link between operating ergo-

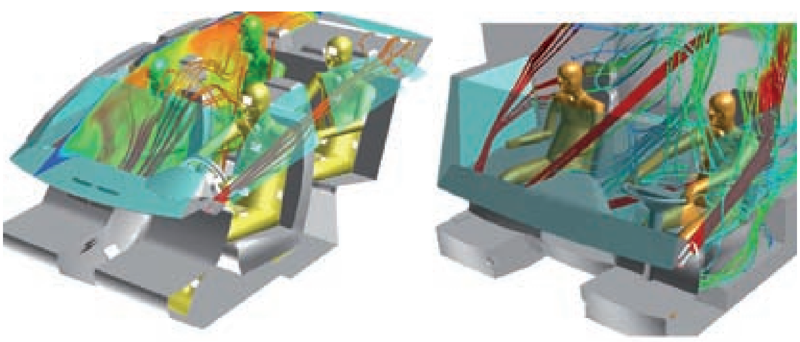

Figure 1: Cabin volume, layout and size of the windshield make up the big difference in the climate control between passenger cars and commercial vehicles

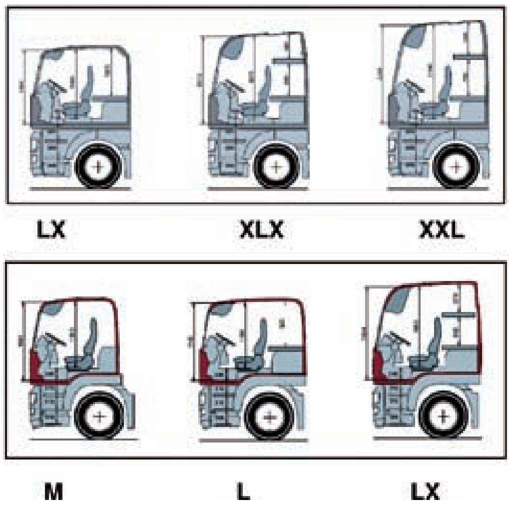

Figure 2: In commercial vehicles, the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software

nomics and traffic safety and a operability studiy carried out with the Technical University of Munich in 2007. Inadequate ergonomics lead to significant risks in traffic situations. The results show that easily recognizable symbols are based on:
- symbols/graphics
- depictions of people
- depictions of seats
- a vehicle contour to back up the symbols
- a combination of text and symbols.

Whereby symbols that are not easily recognized often contain text with no symbols, abstract symbols, or symbols that deviate from the international ISA standard.

The control heads for the MAN TGX therefore reflect the state of the art in relation to operating ergonomics, **Figure 3**.

In the fully automatic air conditioning unit, the driver selects both the desired air distribution and the blower speed by means of two control dials. The driver sets the temperature by means of two buttons, and the selected temperature is shown in a display. In the simpler heating variant, the temperature is set using the left-hand control dial, while the blower speed is changed by means of two buttons. In this A/C control head, particular importance was placed on easily understandable operation and ease of identification of the symbols for the switches and the display by both day and night. This is particularly important for trucks since they are driven for much longer periods, and also at night. It was therefore important to have highly contrasting images and clarity of symbols. This requirement was satisfied in all of the device variants by means of fail-safe LED lights, high-quality plastics technology for the operating buttons, and lasered symbols. In this way, with backlit symbols, no light can escape from the button control panel. Drivers receive an unambiguous acknowledgement from the system via the display in all control head variants, and can thus give their full attention to the traffic.

In the automatic mode of the fully automated system, the blower output temperature adjusts itself independently according to the vehicle's boundary conditions.

All the necessary settings for the air conditioning in the driver's cab and the sleeper cab in the new MAN TGX und TGS vehicles can be operated using a maximum of ten buttons and two control dials. One control head is therefore used to control both the driving and stationary operation. A second control head in the rear is therefore not necessary.

In order to ensure that the device has a long service life and is robust, and requires no maintenance, a non-ventilated interior temperature sensor (ITOS), **Figure 4**, was also used instead of the customary ventilated interior temperature sensor. The cab temperature is measured using the robust and maintenance-free sensor, and this is compensated for by means of a customized control system taking into account the incoming solar radiation, and also the heating of the device itself.

5 The Air Conditioning ECU

In the MAN TGX, a standardized air conditioning ECU was used for the first time. Behr and BHTC are thus responding to customers' demands for ever-smaller packaging dimensions of the control head and an individual design of the instrument panel with maximum control functionality.

For the climate control, a functional separation of the ECU and the A/C control head was selected, **Figure 5**. The heart of the ECU is a printed circuit board of modular construction and of standard dimensions. Thanks to the standard printed circuit board, the dimensions of

Figure 3: The control heads for the MAN TGX / TGL reflect the state of the art in relation to operating ergonomics

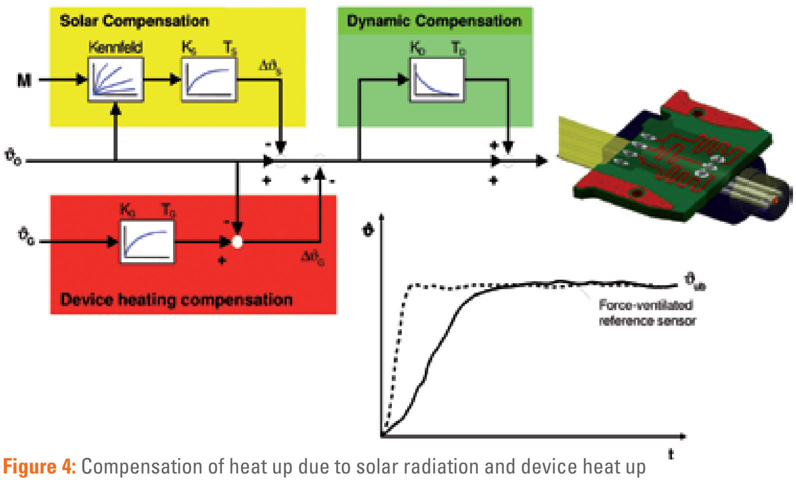

Figure 4: Compensation of heat up due to solar radiation and device heat up

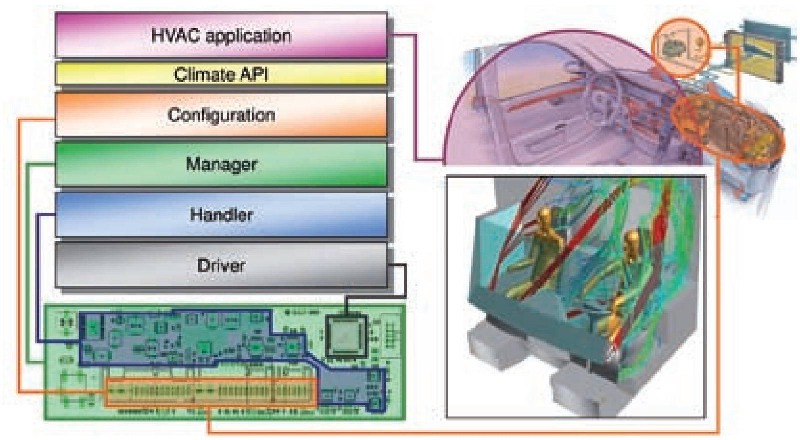

Figure 5: Architecture of the standardized air conditioning ECU – separation of function and design

the ECU and the connector plug are identical for all variants.

The ECU is installed in the vehicle in such a way that the HVAC module and ECU form a functional unit with short electrical connections. A mechanical coupling between the control head and the HVAC module is no longer required. In addition to the preferred mounting position on the HVAC module, other mounting locations in the vehicle are, in principle, also possible.

The open architecture and the less complex design of the control head give the customer more freedom in the design of the instrument panel in the vehicle than before, and better use is made of the existing space envelope. Other variants adapted to the customer's requirements can be obtained only by means of a different assembly and different programming of the processor. This reduces the development outlay required for variants, and cuts costs. The ECU is also flexible in terms of the interface to the customer's preferred data bus format.

6 Summary

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort. Operation of the air conditioning unit must respect ergonomic considerations, so that drivers take advantage of all of the capabilities of the A/C system on the one hand, and are not distracted from the traffic by its operation on the other.

With the unit's design and operating concept, BHTC has satisfied the increasing demands for an A/C control head that is modern, efficient, and at the same time user-friendly.

Whatever the initial climatic conditions at the start of the journey, or however they change during the trip, the climate control system always ensures consistently comfortable and draft-free air conditioning, and thus avoids any additional stress for the driver.

A climate control system that is functionally and ergonomically designed using state-of-the-art processes thus plays a key part in reducing the stress on drivers, and, thanks to the comfortable cab conditions, helps them stay relaxed in every traffic situation.

Non-idle Air Conditioning for Enhanced Road Safety and Reliability

The Author

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Transportation of freight by truck is very important for the functioning of the economy and society. As the driving condition of the driver plays a key role in this, it is essential to provide adequate thermal and acoustic comfort during rest periods. A non-idle A/C system that provides air conditioning both during journeys as well as during rest periods and when the windows are closed, improves driver recuperation. The driver is thus better able to concentrate and feels fitter and more refreshed.

1 Introduction

Transportation of freight by truck plays a key role in the functioning of the economy and society in all Western countries. It is even more important that this transportation takes place in a safe, reliable, and eco-friendly manner, and that it is cost-efficient. Drivers play a key role in achieving this: their health, ability to perform and to concentrate, in short: their driving condition. In order to maintain this condition at a high level for the entire duration of the journey, drivers require a workplace that is ergonomically designed and has a pleasant cab climate.

This involves a high level of thermal and accoustic comfort, which is important not only during the journey itself, but also when any stops are made, whether they are voluntary or involuntary. The thermal comfort is particularly important in driver rest periods, because otherwise the degree of recuperation is reduced. This applies especially to the sleeping phase, since drivers who are not well-rested pose a danger to themselves and to other road users. The infamous "miscrosleep," one of the greatest causes of accidents, is primarily due to inadequate or unrestorative sleep. Non-idle air conditioning, that cools the cabin also during the rest periods with windows closed, enhances the thermal comfort of the driver and thus his ability to concentrate.

2 Driver Survey on the Use of Non-idle A/C Systems

In 2006, Behr surveyed 500 truck drivers from different countries with different vehicles at a total of six rest areas along Germany's main highways. The aim of the survey was to find out how the drivers use the cab as a living space, and what the requirements of this living space are (with a focus on air conditioning), and also what the future requirements of the market are, and which product strategy can be developed from this information.

After this general questioning, 16 drivers were selected for a longer interview. These people formed a representative market cross-section of long-distance drivers who had a non-idle A/C system.

It was found that the great majority of the drivers believe that a non-idle air conditioning unit is important. Around 90 % of the drivers who did not have this sort of system in their vehicle would choose to have one. Since only one fifth of all long-distance trucks are equipped with non-idle vehicle air conditioning, there is a very high market potential. By contrast: parking heating systems are found in all heavy-duty trucks. A summary of the driver's views: Non-idle air conditioning systems ...

– ... are used in a similar way as parking heaters, and are valued just as highly by drivers
– ... are nevertheless available commercially only at a market level of 20 %
– ... are perceived as improving drivers' personal safety
– ... avoid engine idling, and thus prevent fuel consumption and engine wear
– ... should provide air conditioning at night for up to ten hours, and for up to two hours during the day with incoming solar radiation
– ... should provide automatically controlled air conditioning for the entire cab
– ... should not require any servicing or any initial activation.

According to this information, non-idle air conditioning systems have a high market potential. From these and further results of the survey, the following specifications have been provided:

Non-idle air conditioning systems should ...

– ... cool the cab during overnight stops for up to ten hours and for up to two hours during the day (even with strong incoming solar radiation)
– ... provide draft-free cooling of the entire cab (not only the space above the bed)
– ... have automatic temperature control
– ... be reliable and easy to operate
– ... not require any maintenance; the charging of the energy storage devices (cooling battery or battery pack) should occur automatically
– ... be interfaceable with an automatic fresh air supply.

The requested hours of operation and performance can be fulfilled by electrical systems. Also, roof units will fulfill the expectations on non-idle a/c units. The non-idle air conditioning systems currently available on the market are still highly inadequate compared with what drivers want in terms of both their technology and their performance. In order to satisfy all of the requirements of the users, Behr has set itself the following additional design objectives for non-idle air conditioning systems:

– a low current draw in order to allow battery pack operation
– installation in existing roof openings for aftermarket applications
– satisfy truckmakers' installation requirements, specifically in terms of quality, durability and reliability and integration into the operating system architecture.

On the basis of these design objectives, an electric non-idle air conditioning unit

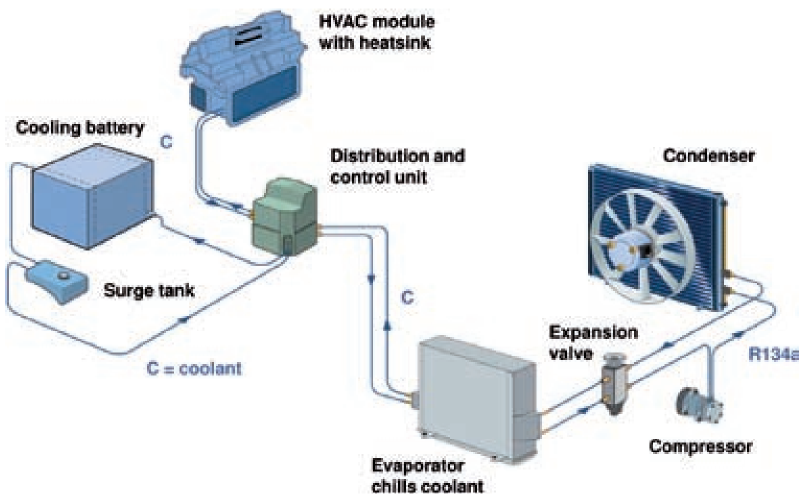

Figure 1: System diagram of the non-idle air conditioning with cooling battery from MAN

in the form of a roof unit was designed and constructed as a demonstration model, in addition to the non-idle air conditioning system with a cooling battery that is already in series production. Design of a rear wall unit is currently under way.

3 Technical Features of the Cooling Battery System

The non-idle air conditioning system with a cooling battery is fully integrated in the vehicle, and replaces the conventional engine-driven air conditioning system. The system has a secondary circuit **Figure 1**. In the charging phase, a conventionally operated refrigerant circuit intensely cools a liquid refrigerant in a special evaporator. This coolant, controlled by the distribution unit, cools both the heat sink in the HVAC module as well as the contents of the cooling battery, which therefore freezes. The heat sink replaces the conventional evaporator in the HVAC module; it cools the cab air during the journey, and during breaks in the journey. In the non-idle A/C system, the refrigerant circuit is in the resting state. By means of the circulating refrigerant, the heat from the vehicle cab is slowly transferred to the cooling battery, where the frozen content of the cooling battery is liquefied. The system with the cooling battery is fitted as standard in the heavy commercial MAN vehicles TGA (since 2003) and the more recent TGX from MAN (since 2007).

4 Technical Features of the Roof Air Conditioning Unit

This plug-in 24-V unit can either be factory fitted or retroffited on the aftermarket. The unit is made up of an electrically operated, conventional refrigerant circuit that essentially consists of a compressor, condenser with fan, receiver, blower, and evaporator with expansion device, **Figure 2**. These components are housed in a single module that projects into the roof opening of the vehicle. Inside the cab, a screen allows drivers to see only the air inlet and the air outlet openings, and the control head. **Figure 3** shows a cross-section through the roof unit installed in the ceiling of the cab, and how it works.

The unit is operated with recirculated air. Control of the fresh air supply is integrated in the control system of the engine-driven air conditioning unit. For the power supply, in addition to the starter batteries, an additional battery pack, for example consisting of lead-gel batteries, must be provided in the vehicle. Some of today's systems are, in fact, powered by conventional starter batteries, but these are not really suitable for operating non-idle air conditioning systems because they are designed to deliver a high current over a short period of time. The non-idle air conditioning system must, however, be supplied with power over several hours. In a nine-hour operation, the battery is almost completely drained, and thus needs to be recharged. If a starter battery was frequently charged and drained, its capacity would quickly be reduced even after 15 such cycles to under 40 %. Starter batteries are therefore unsuitable for this application.

Lead-gel batteries, by contrast, are cycle-proof, that means they can be repeatedly recharged to a high capacity.

The roof air conditioning unit provides sufficient power to air-condition the cab, even with incoming solar radiation during the day. The two-hours-per-day period of operation determined from the driver survey is not, however, the critical value for the battery pack, but instead night operation of up to ten hours. In the case of an average power consumption of the unit of only 400 W, this would require, for example, a battery pack with four standard size traction batteries. The low power consumption of 400 W is the result of the system's exceptionally high efficiency.

Figure 4 uses measured values from the Behr climatic wind tunnel to show the course of air conditioning at night

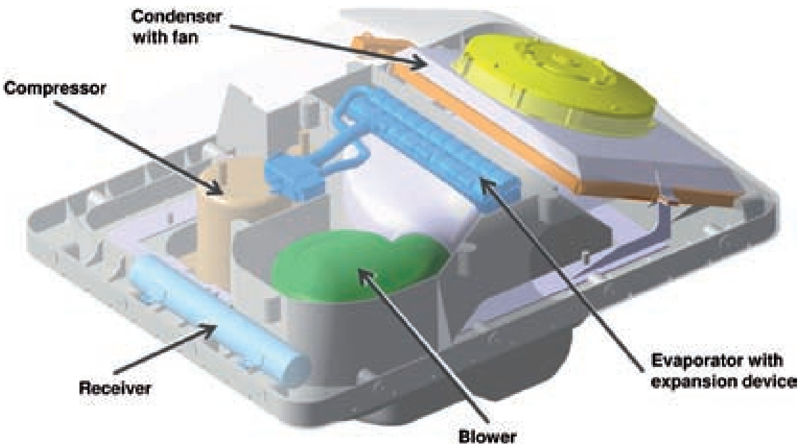

Figure 2: Schematic depiction of the electrial roof air conditioning unit

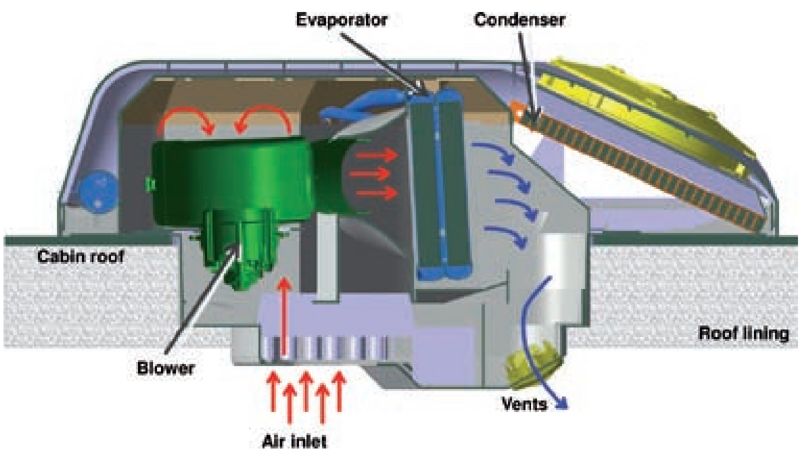

Figure 3: Side view of the electrial roof air conditioning unit

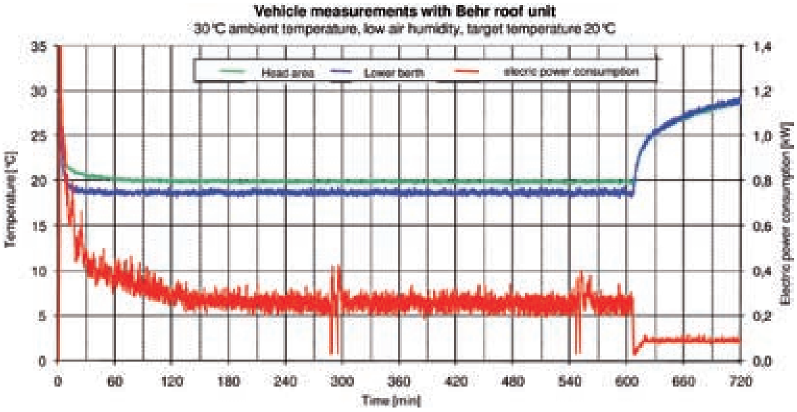

Figure 4: Cool down and power consumption of the electrial roof air conditioning unit at night

with an outside temperature of 30 °C. The target temperature of 20 °C is very quickly achieved and maintained, thanks to the temperature control over the ten hours. The power consumption is almost always less than 400 W.

5 Advantages of the Electrical System

The electrical system has two advantages over the system with the cooling battery: for one thing, drivers can access the cooling capacity at almost any time, because the batteries can store the power supplied by the generator for a long time. They therefore do not need to plan the charging or even to initiate it, since this happens automatically. During the journey, the battery pack is then constantly maintained in the fully charged state. In the system with the cooling battery, the charging of which is initiated manually, it is not possible to exclude the possibility that the driver may one day forget to initiate the charging, or may initiate it too late. If cooling is then required, there may be no or insufficient cooling capacity available. This point was also mentioned in the driver survey, which then also led to the call for an automatic charging of the cooling battery or battery pack.

The second advantage of the electrical system is that, with the battery pack for the non-idle air conditioning unit, additional electrical devices can also be operated, for example a television, computer, microwave oven, or coffee machine. Because the starter battery need not be used to do this, it therefore cannot be drained accidentally.

6 Behr's Development Capacity

As an original equipment manufacturer and systems supplier of passenger car and truck air conditioning units, Behr designs not only the HVAC modules, but also the control heads and associate software, working with joint venture companies such as Behr-Hella Thermocontrol (BHTC). This calls for expertise in the communication processes in the vehicle and for close collaboration with the vehicle manufacturers, for example for the construction of an interface between the engine-driven and non-idle air conditioning systems. Such an interface is required, for example, when the fresh air supply to the cab is to be taken over by the engine-powered A/C system instead of the non-idle air conditioning unit. This is particularly desirable when the truck's engine-driven A/C system is equipped with active carbon filters. In this case, the cab is supplied with filtered, gas-free air that increases drivers' safety when they are asleep. Generally, the fresh air is supplied at intervals, activated, for example, by a timer. The timed control saves battery power, but still guarantees an adequate supply of fresh air.

7 Summary

Non-idle air conditioning systems have considerable market potential, comparable with that of parking heaters, with which almost 100 % of long distance trucks are equipped. Behr's electrical units satisfy all relevant performance requirements, and have proven to provide a higher cooling capacity and higher efficiency than all comparable systems. A further advantage of the Behr units is their reliability, because the system components were designed specifically for use in trucks, and are sourced from series production of vehicle air conditioning units. ■

Measures for Satisfying Future Exhaust Emissions Standards in Special-purpose Vehicles

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US '10 envisages another drastic reduction in NO_x emissions for commercial vehicles.

1 Behr Industry

When Behr Industry was founded in 1990, the objective was to cater to special markets in the engine cooling and air conditioning sectors. The justification for this was that technical and legal requirements were made with respect to the components and systems of off-highway vehicles that were completely different from those for the passenger car and commercial vehicle markets – requirements that cannot be satisfied by simple modification of an existing component or of an existing system.

The split of Behr Industry and Behr GmbH & Co. KG essentially reflects our customer structure, since Behr's customers often operate in different market segments, and under different names. Today, Behr Industry is active in the markets for buses, heavy-duty engines, railway vehicles, aircraft, construction and agricultural vehicles, electronics, military products, and gensets (that means diesel-engine driven generators for generating electricity). The most important requirements are:

- The smaller production volumes or even single unit productions, also mean, that different development procedures, manufacturing technologies, and logistic concepts are necessary.
- The Euromot, EEV, and Tier X legislation governing emissions and CO_2

emissions is very similar to the Euro 5/6 and US 'XX standards from the car and truck vehicle sectors – only time-displaced by about three years.
- Other constraints on cooling requirements, installed position, and the available installation space.
- In the special-purpose vehicles, the components and systems are exposed to different stresses: fouling through mud, dust, and fibers results in different focuses for the development of heat exchangers. In some shipbuilding applications, cooling takes place using the seawater itself. The corrosive action of the saltwater is countered with special stainless steel.

2 Small-scale Series Production

For example for buses, small-scale series production specifically means annual volumes of approximately 500 to 3000 units. In the case of railway vehicles, the figure can be as low as just five to 100 units per year. Behr Industry must therefore use other processes for manufacturing radiators and coolers and for assembling complete cooling systems. Semi- or fully automatic production equipment can be used only rarely, and the costs of die-casting or functional plastic components often cannot be redeemed, owing to the high capital costs involved. Flexible systems are called for that require little or no capital expenditure; however, these demand higher manual production outlay and highly skilled manufacturing staff. Behr Industry also endeavors to carry over products or components from high-volume series production and integrate them (for example buses and tractors) in order to take advantage of the cost benefits of large-scale series production. This significantly reduces R&D expenditure, validation requirements, and the risk of failures in the field.

Behr Industry also employs the general Behr production standards and development tools and tests and develops its products in the test facility of the parent company, and uses the same simulation tools (FE analyses, CFD calculations, BISS). This makes the development of new products specifically catering to special market requirements efficient and competitive.

3 Exhaust Emissions Standards

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US 10 envisages another drastic reduction in NO_x emissions for commercial vehicles. The corresponding standard for the off-highway sector is Euromot stage IIIB / Tier IV A, and will come into effect approximately three years after Euro 5 / US 10. The limits for NO_x and particulate emissions are not much different from those of commercial vehicles: Euromot stage IIIB envisages a reduction of nitrogen oxide emissions to 2 g/kWh, and of particulate emissions to 0.025 g/kWh (Euro 5 specifies 2.0 NO_x and 0.2 PM).

The exhaust emissions standards for off-highway vehicles in the USA are similar. The standards that are similar to the US07 and US10 standards are the Tier 4a and Tier 4b standards, which will come into effect at the same time as Euromot stage IIIB, that means three years later.

In the bus market, we find a special situation; here, the EEV (Enhanced Environmental Friendly Vehicle) preliminary standard was introduced. EEV is not a mandatory limit, but rather a voluntary standard that is virtually no different from Euro 5 in terms of the limits on NO_x and particulate emissions. EEV engines essentially already satisfy the Euro 5 standard that will be in force from 2009. The environmental awareness of the bus operators, in particular in large cities, leads to their voluntarily complying with special limits as per EEV.

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In order to comply with the exhaust emissions regulations and to save fuel in off-highway applications, as in the case of commercial vehicles, systems such as cooled exhaust gas recirculation or two-stage turbocharging are used, **Figure 1**. Here, too, this similarly leads to increasingly complex cooling systems every time the exhaust emissions laws are tightened further. Higher charge air temperatures and pressures and quantities of heat in the coolant call for new solutions for heat exchanger design. The integration of cooled exhaust gas cooling and indirectly cooled charge air requires considerable systems expertise in order to be able to guarantee the necessary cooling within the special constraints of the off-highway market.

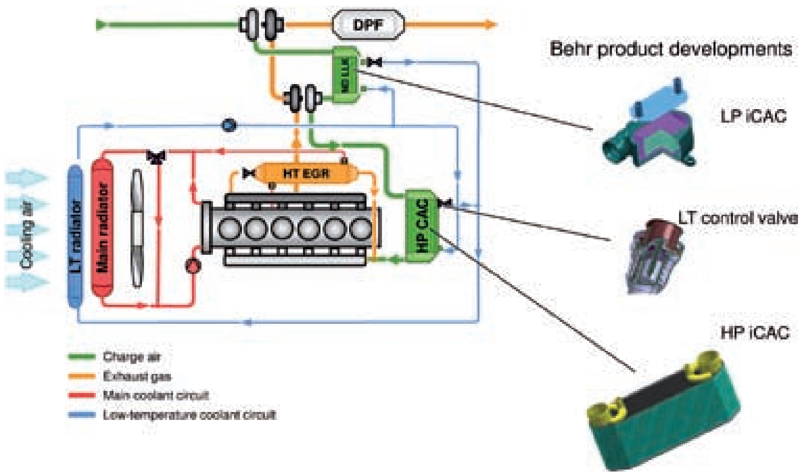

Figure 1: Schematic representation of a two stage turbocharging with indirekt charge air cooling

4 Fouling

A distinctive feature of special-purpose vehicles is their use in very different areas of application: mines, fields, rails, water, construction sites, forests, or garbage dumps. Fouling on the external surface through which cooling air passes thus takes very different forms. Sand, dust, oils, pollen, leaves, plant debris, grass, litter, and many other soiling agents in every possible combination accumulate on the air side inside the radiator and between the fins, Figure 2. This leads to a higher air-side pressure loss and restricts the flow of cooling air. The radiator can no longer provide the desired cooling power to the engine, and engine performance decreases accordingly.

Here, conventional radiators with louvered corrugated fins cannot be used. Behr Industry has developed special cooling air fins specifically for these applications. Unlike conventional fins, these do not have any louvered structure on their surface; instead, they are flat or corrugated. In car or truck radiators, these louvers serve to improve heat transfer between the cooling air and the cooling water, because the air does not pass through the fins in a laminar flow, but instead turbulence is produced on the louvers, Figure 3. However, a lot of dirt particles collect on these louvers that cannot be removed by using compressed air, for example. If there are no louvers, dirt particles can be blown away against the direction of flow.

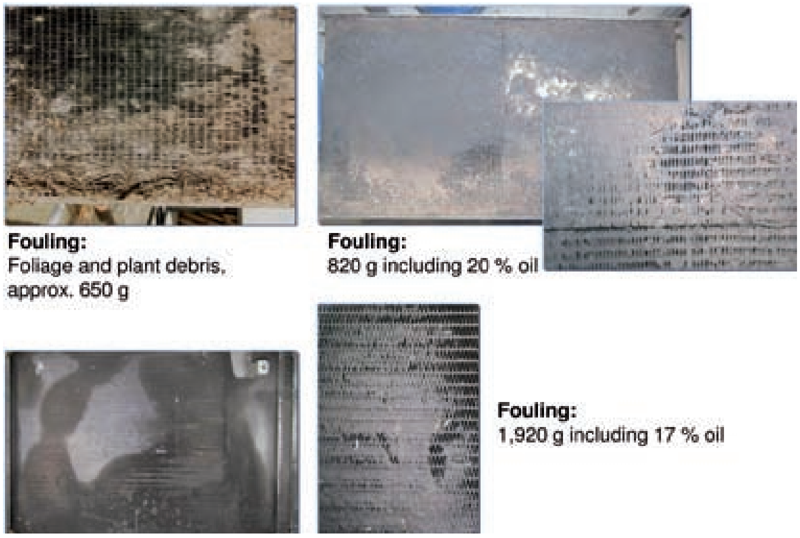

Figure 2: Representative examples of different foulings as found in off-highway applications

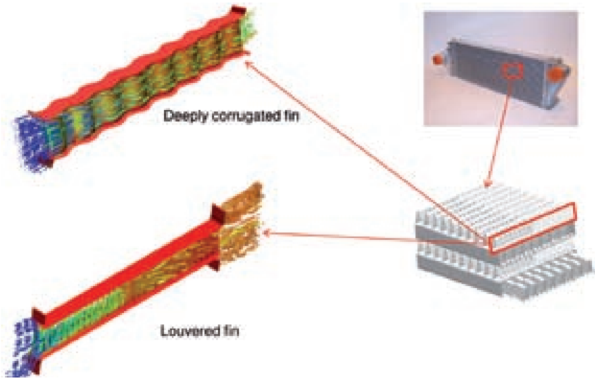

Figure 3: Comparison of a deeply corrugated fin and a louvered fin

In order to understand the mechanisms of fouling and to draw the appropriate technical conclusions, Behr Industry has been working closely with a number of institutes for several years. Figure 4 and Figure 5 show the results of tests on different cooling air fins that were realized in collaboration with the ILK Dresden (Institute of Air Handling and Refrigeration Technology in Dresden). These tests investigated to what extent the pressure drop on the cooling air side is dependent on the dust concentration and the fin used. It was found that the flat fin has the smallest pressure drop. Figure 5 shows the results of similar tests, but under more realistic conditions using fibers as the fouling agent. A flat fin, a staggered fin and a louvered fin were exposed to fibers during usage and the cooling air side pressure drop was measured over time. After a predetermined cycle had been completed, the fins were cleaned with compressed air. It is observed that the pressure drop in the louvered fin is worse after every cleaning cycle compared with the flat fin and the fin with deep corrugations. This is because fibers penetrate deep inside the fins, and, in the louvered fin in particular, can then no longer be removed. Therefore, over time, the radiator with the louvered fins becomes clogged up, and can no longer be cleaned.

Of course, the efficiency of the radiator decreases with the soiling of the louvers. Together with our customers, we must therefore arrive at a compromise between the prevention of fouling and the performance density of the radiator.

Furthermore, the arrangement of the individual coolers (radiator, charge air cooler, etc.) can play a role in minimizing the susceptibility of the cooling module to fouling. In conventional radiators, the individual radiators are arranged one behind the other ("face to face"). The problem here is that dirt particles may pass through the first radiator and become caught in the second one. For cleaning, the cooling module would have to be dismantled. To avoid this, the radiators can be arranged next to one another ("side by side"), so that all of the faces can be cleaned from the outside. Alternatively, the frame of the cooling module can also be designed to swing open, in order to facilitate cleansing of the second radiator, Figure 6.

5 Systems Expertise

All of these requirements must be implemented for a small market that individually caters to specific customers. Behr Industry provides not just the coolers and

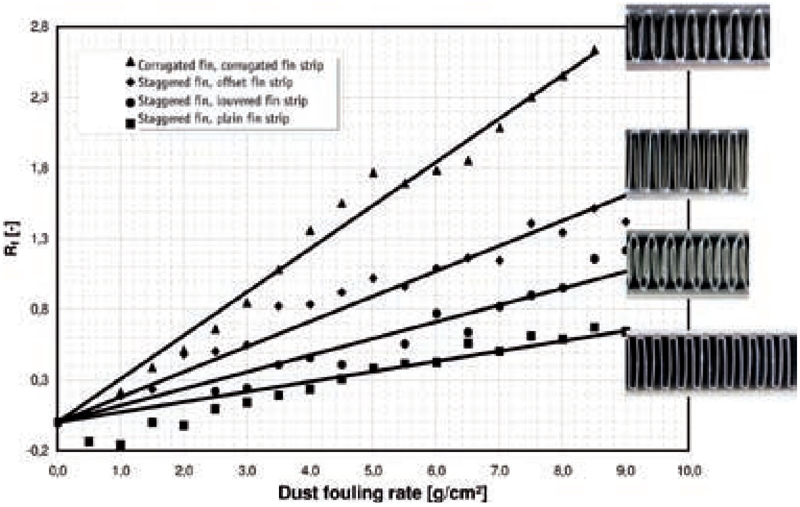

Figure 4: Fouling: Impact of dust on the pressure loss in coolers. Investigations performed by ILK Dresden on behalf of Behr Industry

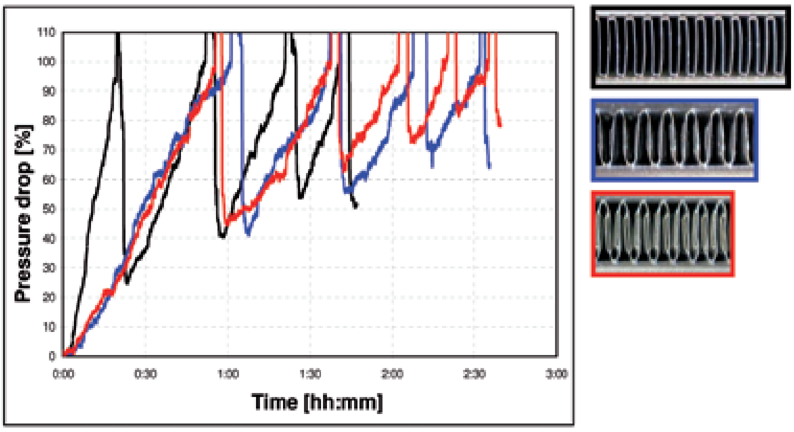

Figure 5: Fouling: Impact of fibers on the pressure loss in coolers and the regeneration of coolers with different fins. Investigations performed by ILK Dresden on behalf of Behr Industry

Figure 6: Solutions designed to prevent fouling – cooling module for city bus featuring swing-out device (top); tractor cooling module with coolers arranged in parallel on the cooling air side (bottom)

radiators themselves, but also complete ready-to-install cooling systems including the radiator/coolers, fan, fan drive, frame, and, if required, also the surge tank, water and oil pumps, and level controller, working in close collaboration with and for its customers.

When solving these technological problems, Behr Industry calls on Behr's development methods, results and products, as they are described in the article "Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles". Behr Industry uses this technology and adapts it to suit the respective engines and the needs of the different special markets. Indirect charge air cooling is standard in commercial vehicle engines. The corresponding indirect charge air coolers are designed in a stacked plate construction. Behr Industry adapts the coolers for a potentially higher engine power. This can be achieved with a simple scaling, that means an increase in the quantity of stacked plates, for example, or, alternatively, by means of bundling existing EGR coolers when there are very high quantities of exhaust gas in the cooled exhaust gas recirculation, for example.

Because the installation position of the engines in special-purpose vehicles is often different from that of conventional commercial vehicles, adapting the components for the new installation position represents another challenge.

If the installation position changes, very often the air ducting on the cooling module or the position of the surge tank relative to the radiator changes as well. In conventional applications, the cooling air is routed from the front through the radiator into the engine compartment. In railway vehicle applications, for example, this is often not possible, owing to the installation position. In roof units, the air is conveyed laterally through the radiator and leaves the module at the top. In other locomotive applications, the radiators are located at the bottom of the module and the cooling air is routed through the assembly from the top to the bottom. If the surge tank for the cooling medium cannot be mounted above the radiator, technical solutions such as an anti-cavitation tank or two-chamber system must be found in order to ensure that the cooling circuit remains free of air. ■

In recent years Behr has made such progress in developing cooled exhaust gas recirculation and iCAC systems that commercial vehicle manufacturers now have at their disposal reliable, production-ready solutions for reducing NO_x emissions. When used in combination, these new cooling systems can meet Euro 5 emissions requirements without the need for a special exhaust treatment process such as selective catalytic reduction (SCR).

Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles

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1 Introduction

And in contrast to SCR, these innovations do not require any additional operating agent. When they are used in conjunction with the latest engine and injection technology there is no increase in fuel consumption, and they also allow weight reductions at comparable costs. Further benefits are the flexibility of application of these new solutions, and their high potential for further development to meet Euro 6 requirements.

2 Emissions Standards and Reduction Technologies

2.1 Emissions Standards

Since 1992 (Euro 1), the limits for heavy trucks have been brought down in five stages, including some very drastic reductions. Since 2000 (Euro 3) emission limits for NO_x have been reduced from 5 to 2 g/kWh, and particulate emissions from 0.10 to 0.02 g/kWh. In percentage terms this corresponds to a 60 % reduction for NO_x and 80 % for particulates.

2.2 Exhaust Air Cooling and Charging

The exhaust gas recirculation process is essentially based on the fact that the exhaust gas has a higher heat capacity and a lower oxygen content than air. This causes the combustion temperatures in the cylinder to fall. The cooling of the exhaust gas and the charge air makes the temperatures drop even further. Because NO_x formation is an exponential function of these temperatures, a combination of cooled exhaust gas recirculation and turbocharging with CAC was able to meet the Euro 4 limits. Compliance with the stricter requirements of Euro 5 requires either an increase in EGR rates or a reduction in exhaust gas and charge air temperatures. The single stage EGR with two stage turbocharging plus intercooling, and two stage cooled EGR with single stage turbocharging are available for this purpose.

3 Engine Cooling Systems for Euro 5

Over the last few years Behr has been investigating how the increasingly stringent limits can be met by improving engine cooling. In particular, efficient charge air and exhaust gas cooling have a positive effect both on NO_x formation in the combustion chamber and fuel consumption. The newly developed production-ready engine cooling systems for Euro 5 and their components are described below, including comparisons with the SCR system.

3.1 Engine Cooling System with Single Stage Exhaust Gas Cooling and Two Stage Turbocharging

Figure 1 is a functional schematic of such a cooling system. It comprises an exhaust gas cooler which is cooled by the engine coolant, and a low temperature (LT) cooling circuit which contains two charge air coolers and a low-temperature radiator. Since the LT-radiator has a large frontal area and is the first cooler to be exposed to the cooling air flow, very low charge air temperatures can be obtained. This type of CAC is called indirect CAC.

In the EGR cooler, **Figure 2**, the exhaust flow component for recirculation, removed from the engine at the exhaust manifold, is cooled and then added to the charge air upstream of the intake manifold. This causes the temperature of all the intake air to be lowered, which reduces the production of NO_x. However, single stage EGR cooling as used for Euro 4 is not sufficient for Euro 5; this requires either more intensive cooling or an increased EGR rate. For the latter, in order to provide a sufficient oxygen concentration in the cylinder, it is necessary to have a higher charge pressure, which in this system is obtained using two stage turbocharging with intercooling. Two stage turbocharging enables a constant engine output to be maintained in spite of increased EGR rates, and prevents any increase in particulate emissions.

In both charge air coolers the charge air, which undergoes intense heating in each of the two compression stages, is cooled back down and some of the heat which was absorbed is transferred to the liquid coolant. In the LT-radiator this heat is then dissipated into the ambient air. This radiator is installed in the vehicle frontend, which in today's truck diesel engines is the normal location for the conventional charge air cooler, connected to the turbocharger and to the intake manifold of the engine via bulky air ducts. These ducts can be eliminated with indirect CAC, which saves space and simplifies packaging.

The indirect charge air cooler can have a very compact design thanks to its high level of efficiency (compared to a charge air-to-air cooler), and this makes it possible to place the cooler between the turbocharger and the intake manifold. This also means that the charge air ducts do not need to be diverted. The charge air pressure loss can thus be reduced by up to 50 % and the charging pressure can be increased accordingly, which both improves cylinder air filling and simplifies the gas exchange process. Both factors reduce the fuel consumption at a given output.

Dispensing with the air ducts also reduces the air volume in the system. In a 12-l diesel engine a reduction of the air volume of more than 50 % was achieved thanks to iCAC. As a result the system reacts more quickly to load changes. Unlike the situation in passenger cars, however, in commercial vehicles it is not a matter of rapidly increasing torque, but of preventing emissions, for example particulate emissions. The well-known cloud which a truck without a particulate filter produces when the driver suddenly accelerates, happens because the turbocharger cannot supply the amount of air required for full-load operation straight away. There is then not enough oxygen for full combustion of the fuel, and particulate formation briefly increases rapidly. The smaller air volume thus reduces particulate emissions into the environment or the charge build-up on the particulate filter.

The intercooling of the charge air has a positive effect on the efficiency of the second charger. The charging pressure, which today involves pressures of up to 3.6 bar in the case of single stage turbocharging, can reach values of 4 to 5 bar absolute with two stage turbocharging and intercooling. As already described,

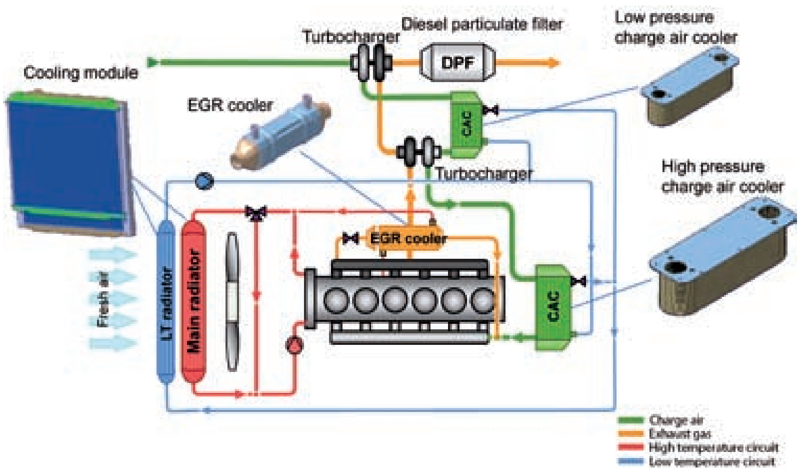


Figure 1: Engine cooling system with single stage EGR cooling and two stage turbocharging

this makes it possible to increase the EGR rates without reducing performance or increasing particulate emissions. Furthermore, a higher charging pressure theoretically opens up the following optimization opportunities:

- Increase in the power density (power per unit of displacement) of the engine. This leads either to increased engine output for the same displacement or smaller displacement for the same engine output ("downsizing"). The latter in particular has a positive effect on fuel consumption due to reduced friction in the engine.
- Increase in the excess air in the cylinder. Owing to the higher oxygen concentration in the cylinder this has a positive effect on soot formation. In other words the fuel is almost completely burned up, and less particulate matter is produced.

3.2 Engine Cooling System with Two Stage Exhaust Gas Cooling and Single Stage Turbocharging

In this system, **Figure 3**, the exhaust gas to be recirculated is first fed to an exhaust gas cooler which is cooled by the engine coolant. It is then routed to a second cooler which, as shown in the functional diagram, is located next to the charge air cooler. In this cooler the exhaust air is cooled by the ambient air. The air flow required for this is produced by the fan and/or by the airflow past the vehicle, according to the travelling speed.

Since the exhaust air is cooled in two stages in this system, resulting in lower exhaust gas temperatures, single stage turbocharging with CAC is sufficient to meet Euro 5 requirements. The charge air is cooled by the ambient air as in a conventional charge air cooler. This is why it is installed at the front of the vehicle where the ambient air flows through it. In this cooling system the exhaust gas and charge air can be brought to approximately the same temperature levels, which significantly lowers the mixing temperature upstream of the Intake manifold. In contrast to the shown separate arrangement of the charge air cooler and exhaust air cooler, this is an integrated cooler, that means a single unit comprising the charge air cooler and the exhaust air cooler.

4 Product Innovations

4.1 Integrated Exhaust Gas Cooler and Charge Air Cooler

The system consists of series-connected individual exhaust gas coolers, **Figure 4**, operating with different cooling media: engine coolant and ambient air. The air-cooled EGR cooler is integrated into the charge air cooler. This form of integration is the first of its kind worldwide.

The exhaust air cooling process: the exhaust gas flows from the cylinders are brought together in the exhaust manifold. From there some of the exhaust flows into the exhaust gas (top right, Figure 4). In this first stage of exhaust gas cooling the exhaust gas is cooled by the engine coolant. This part of the exhaust flow is then conveyed to the second stage, the air-cooled EGR cooler, integrated into the top area of the charge air cooler. When ambient air temperatures are low, the air-cooled exhaust gas cooler can be circumvented by means of a bypass in order to prevent the cooler from freezing. In both cases the exhaust gas then enters the intake manifold and the individual cylinders. It has first been mixed with the charge air cooled in the charge air cooler, so that the intake air has a uniform composition and temperature, which is important for ensuring the same combustion process in all cylinders.

In the first stage of exhaust gas cooling the exhaust gas temperature is reduced to 200 to 150 °C. In the second stage, the low temperature stage, it is then reduced to 25 to 20 K above the ambient air temperature. This lowers the temperature of the intake air overall, based on the mix ratio of charge air and exhaust gas.

The core of the air-cooled EGR cooler consists of tubes conveying exhaust gas and corrugated fins lying between them. In this cooler too, the tubes have been stamped inside to form turbulence-generating winglets.

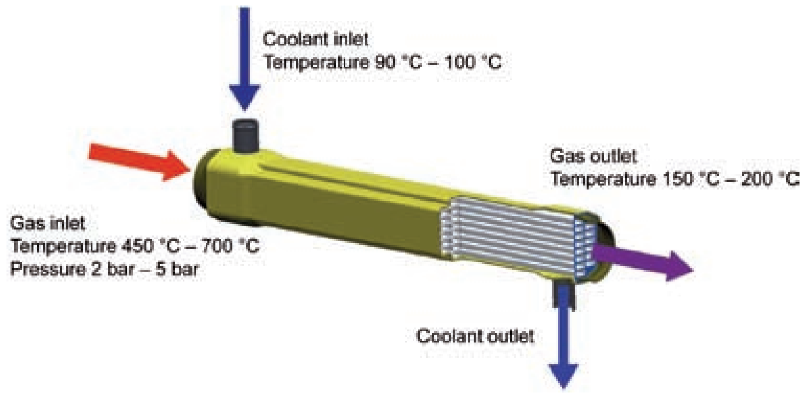


Figure 2: EGR cooler

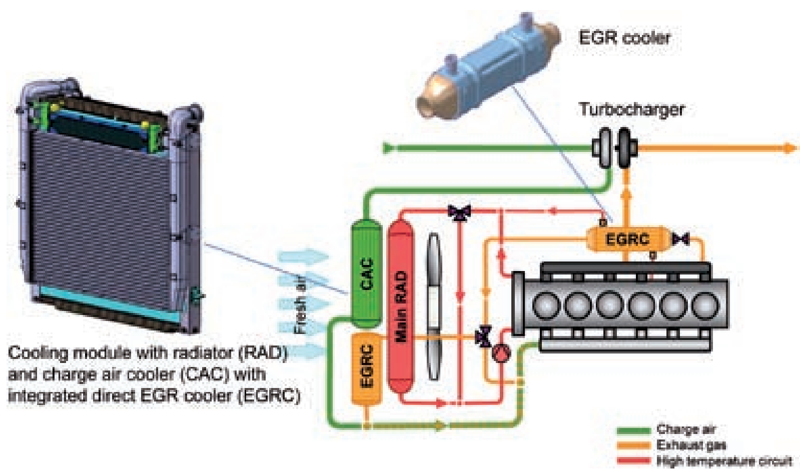


Figure 3: Engine cooling system with two stage EGR cooling and single stage turbocharging

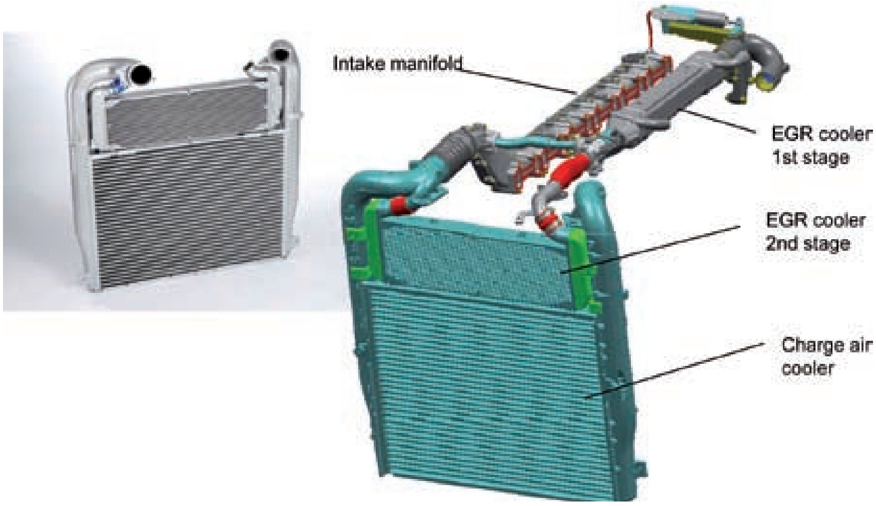


Figure 4: Two-stage EGR cooling: 1st stage coolant cooling, 2nd stage air cooling. EGR cooler integrated in charge air cooler

Figure 5: NFX 750 fan with ERS 250 fan drive

The tubes and corrugated fins are bonded together in a brazing process whereas the pipes and exhaust gas tanks are welded. The cooler consists of corrosion-resistant stainless steel tubes and corrugated fins and the exhaust gas tanks are also made of stainless steel. Features of the integrated charge air/exhaust air cooler module:

- optimized loss of pressure in exhaust gas and charge air cooler
- good mixing of charge air and exhaust gas at the mixing point
- bypass prevents freezing of the exhaust gas cooler
- no return flow of condensate into the charge air cooler
- EGR cooler is corrosion resistant.

4.2 iCAC with Integrated Thermostat

The higher EGR rates for Euro 5 compared to Euro 4 also necessitate higher charging pressures, leading to an increase in the charge air temperature. The charge air coolers used must therefore be able to withstand temperatures of more than 220 °C and pressures up to 5.1 bar absolute. Changes to the design of the charge air cooler can reduce the level of stress, which is based on the pressure and temperature load, to such an extent that the coolers are able to withstand the higher loads.

This aspect was taken into account from the outset for development work on the indirect charge air coolers and, as in the case of the charge air/EGR cooler module, development results were checked with stress analyses using the finite element method (FEM). The indirect charge air cooler is a stacked plate system comprising plates for the charge air and the cooling water ducts. Between the plates there are turbulators for the charge air and the coolant, which are optimized for heat transfer and temperature and pressure requirements.

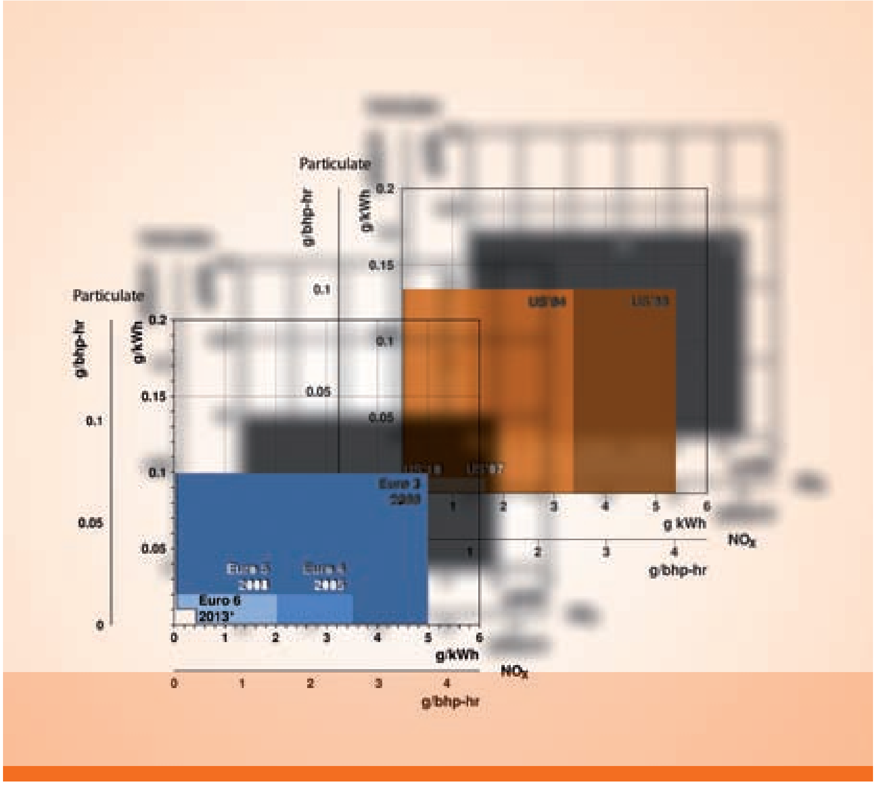
The charge air cooler is operated in a counterflow arrangement, that means the hot charge air flows in on one side and is cooled with cooling water flowing in the opposite direction. It was decided to use two intake ducts for coolant distribution. The coolant flow rate is controlled by means of temperature-controlled choke thermostats at the coolant outlet of the charge air cooler. According to the heat input from the hot charge air, the coolant flow rate is very quickly adjusted by means of fast-responding wax elements, thus avoiding the need for a complex control system.

4.3 Fan and Fan Drive

Fan output has been improved with the new NFX 750 fan, **Figure 5**. The modified blade geometry and higher number of blades (increased from eight to eleven) has boosted fan output while retaining almost the same axial construction depth as in the current series-produced model. The higher fan efficiency has also allowed the drive power to be reduced by approximately 10 % for the same mass air flow. The fan is driven by the Visco ERS 250 fan clutch. This electronically controllable clutch can transfer 40 % more torque than currently used fan drives with comparable size, along with significant improvements in controllability and dynamic clutch response. This means even more precise fan activation than before in response to the actual cooling demand, allowing the complete elimination of superfluous fan noise.

In order to cool the Visco fan drive sufficiently to accommodate its high operating range, the fan hub design has been optimally adapted to the clutch. Flow dividers and flow stabilizers in the region of the fan hub ensure that the inflowing cool air is conveyed through the cooling fins of the clutch and can then flow unobstructed through the fan blades. The result is improved cooling of the silicone fluid in the clutch and a higher slip power tolerance. Another effective means of protecting the silicone fluid in the clutch from overheating is continuous simulation of the silicone fluid temperature in the engine control unit. ■

The NO_x and particulate matter emission limits at Euro 5 and US 2007 (abbreviated as US '07) for commercial vehicle engines are a major challenge for engine and exhaust gas aftertreatment technology. US '07 is already in effect; Euro 5 will come into force in October 2008. Even more demanding technological challenges are to come: from January 2010, US 2010 (US '10) limits will apply in the USA, and the introduction of Euro 6 is expected in 2013. However, the commercial vehicle engines, which will have to meet those limits are being designed now. Behr's low temperature exhaust gas recirculation provides an appropriate technology for these engines.



NO_x Reduction Potential of Cooled Exhaust Gas Recirculation in Euro 6 Commercial Vehicles

The Author

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1 NO_x and Particulate Limits

The Table (top) shows how far the limits have reduced from Euro 3. The Euro 6 values are still to be finalized but will involve drastic reductions: in the case of nitrogen oxides (NO_x) probably by more than 80 % (from 2.0 to 0.4 to 0.7 g/kWh) and for particulate matters (PM) by more than 50 % (from 0.02 to less than 0.01 g/kWh). In the USA the forthcoming US '10 limits for NO_x are 0.20 g/bhph (approximately 0.27 g/kWh) and for PM 0.01 g/bhph (approximately 0.0134 g/kWh), Table (bottom). Of course the new limits should be met with the minimum fuel consumption penalty.

2 From Euro 5 to Euro 6

A very important step towards reducing NO_x and particulates in recent years has been the further development of the combustion system. Optimized combustion chambers, improved fuel injection

and turbocharging with charge air cooling meant that it was possible for commercial vehicle engines to comply with the Euro 3 NO_x limits without any special exhaust gas aftertreatment. However, by the time Euro 4 came into being these techniques were, for the most part, no longer sufficient. To meet the new standards additional measures were required.

In terms of internal engine measures, however, it is not possible to minimize both NO_x and PM emissions at the same time (the NO_x/PM trade-off). A viable method of achieving this goal is to minimize one component inside the engine, for example NO_x, and the other outside the engine: in this case the particulates, using a particulate filer. Conversely, reducing particulates by measures inside the engine means that NO_x reduction has to take place downstream of the engine, for example by means of the process of selective catalytic reduction, SCR.

Behr worked together with engineering consultant AVL to investigate the NO_x reduction potential of SCR and cooled exhaust gas recirculation (EGR) technology. The findings indicate that both SCR and cooled EGR are viable options for Euro 5, **Figure 1**.

Euro 6 will require enhancements to the Euro 5 technology, as illustrated in **Figure 2**. Possible concepts are:

- SCR: Selective catalytic reduction, normally combined with single stage charge air cooling.
- EGR: Cooled exhaust gas recirculation combined with two stage turbocharging with intercooling. The exhaust gas cooling also takes place in two stages: a 1st stage of high temperature exhaust gas cooling (HT-EGR), and a 2nd stage of low temperature exhaust gas cooling (LT-EGR).
- SCR plus EGR: combinations of SCR technology and cooled exhaust gas recirculation are also possible. Boosting takes place in a single stage and exhaust gas cooling is a two stage process with high and low temperature stages (HT and LT stages). Other combinations are also possible. However, the common feature in all of these is that they are complex, expensive and require considerable space.

All systems require a diesel particulate filter (DPF) to reduce PM emissions.

3 Selective Catalytic Reduction

The SCR technology already used in Euro 4 and Euro 5 systems for commercial vehicles is based on the addition of urea in the form of an aqueous solution (Adblue) to the exhaust gas flow. Hydrolysis of the urea produces ammonia, a NO_x reducing agent which converts the NO_x into steam and nitrogen in a special catalytic converter. The complete exhaust gas aftertreatment system in this case consists of a diesel oxidation catalytic converter (DOC), a DPF, a hydrolysis catalytic converter (HC), a SCR catalytic converter (SCR cat) and trap catalytic converter (TC), and the Adblue tank and a metering unit.

However, the extremely low Euro 6 and US '10 limits probably cannot be met with catalytic NO_x reduction alone. This is because of the new test cycles for measuring the emissions. Instead of the ETC (European Transient Cycle) currently specified, for Euro 6 it is likely that the new WHTC (World Harmonized Transient Cycle) will be used. This cycle results in lower engine speed and load overall and, therefore, lower exhaust gas temperatures.

However, low exhaust gas temperatures reduce the generation of ammonia from the urea solution. Additionally, at low temperatures the catalytic converter also loses some of its efficiency. Thus the

Table: NO_x and particulate emission limits for heavy duty trucks (> 3.5 t) for Europe (top) and the USA (bottom)

Phase	Introduction date	NO_x [g/kWh]	Particulate [g/kWh]	Test cycle
Euro 3	October 2000	5.0	0.10 (0.16)	ESC (ETC), ELR
Euro 4	October 2005	3.5	0.02 (0.03)	ESC (ETC), ELR
Euro 5	October 2008	2.0	0.02 (0.03)	ESC (ETC), ELR
Euro 6*	2013	0.4 – 0.7	0.01	WHTC, WHSC

ESC: European Steady State Cycle
ETC: European Transient Cycle
WHSC: World Harmonized Steady State Cycle
ELR: European Load Response Test
WHTC: World Harmonized Transient Cycle
Values in parenthesis: ETC
Introduction date for new type approvals; for all type approvals normally one year later
Limit values for CO and HC not shown here
* Euro 6 not defined specifically, decision expected in 2008

Phase	Introduction date	NMHC + NO_x [g/bhp-hr]	NO_x [g/bhp-hr]	Particulate [g/bhp-hr]	Test cycle
US'98	January 1998	-	4.0 (5.36)	0.10 (0.134)	HD-FTP
US'04	January 2004	2.5 (3.35)	-	0.10 (0.134)	HD-FTP, SET
US'07	January 2007	-	1.2 (1.61)	0.01 (0.0134)	HD-FTP, SET
US'10	January 2010	-	0.2 (0.27)	0.01 (0.0134)	HD-FTP, SET

HD-FTP: Heavy Duty Federal Test Procedure
SET: Supplemental Emission Test
Values in parenthesis: g/kWh (conversion factor: 1 g/bhp-hr = 1.34 g/kWh)
Limit values for CO and HC not shown here

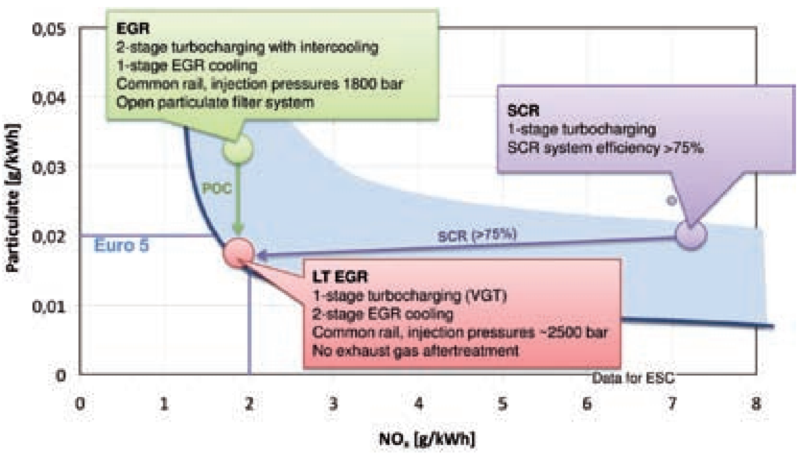


Figure 1: Technologies for Euro 5 – state of the art for the NO_x/PM trade-off

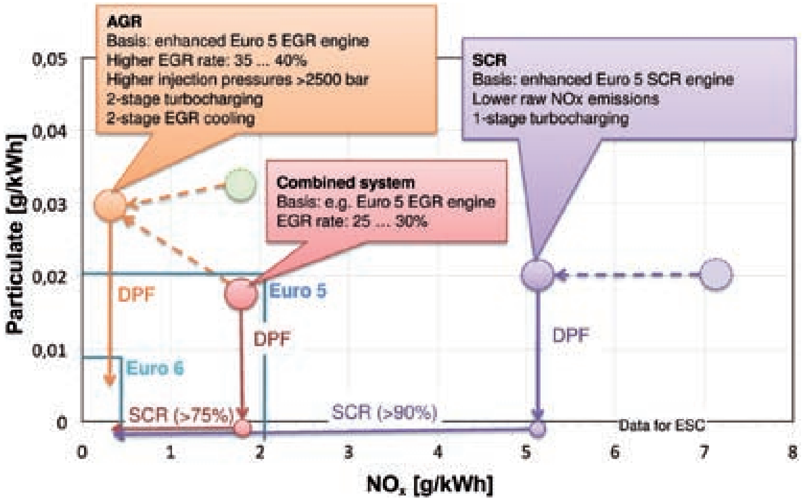


Figure 2: Technologies for Euro 6 – enhancements based on Euro 5

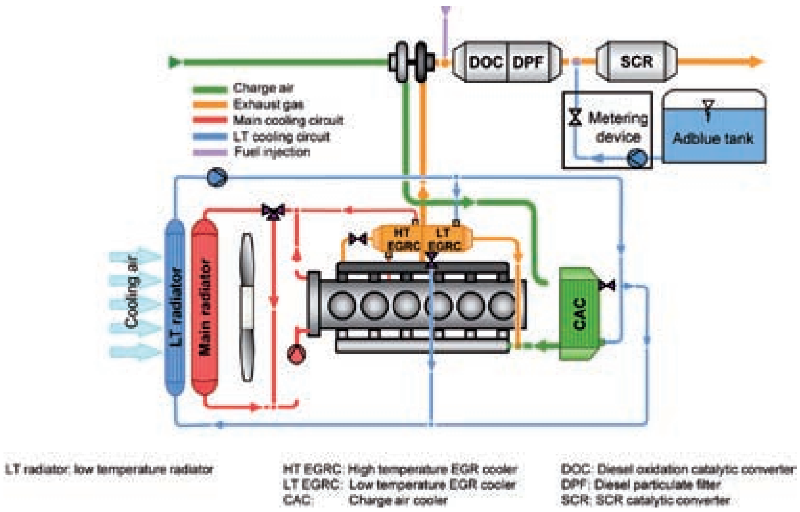


Figure 3: Combined system for Euro 6: EGR and SCR

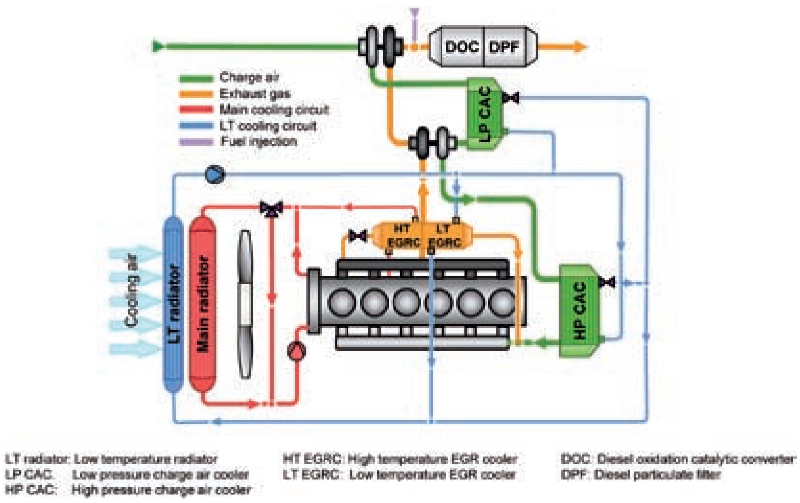


Figure 4: Potential two-stage EGR system for Euro 6

NO_x conversion rate is limited in two ways. In addition, the WHTC includes a cold test which further reduces the rate of conversion in the first part of the cycle. The resulting increase in NO_x emissions probably cannot be offset in the second hot parts of the test.

The transition from Euro 5 to Euro 6 requires an 80 % reduction in NO_x emissions. If this objective is to be achieved with selective catalytic reduction alone, the efficiency of the technology will have to be significantly increased, from around 75 % today to more than 90 %. That is not all: to offset the temperature effect from the new test cycles as described above it will be necessary to further boost the efficiency of the SCR system. Accordingly, it may be difficult to meet Euro 6 and US '10 using SCR alone.

One possible method for achieving the Euro 6 legislation would be to combine SCR and EGR technology, **Figure 3**. Since cooled EGR means less NO_x is produced in the engine, there is also less NO_x to be converted by catalytic reduction in the exhaust system. The drawback of this combined system, as mentioned previously, is its size and complexity.

4 Exhaust Gas Recirculation with Two Stage Cooling and Two Stage Turbocharging with Intercooling

4.1 Two Stage Exhaust Gas Cooling

Exhaust gas recirculation reduces the oxygen concentration of the cylinder charge, thus reducing the speed and temperature of combustion. Since the rate of NO_x formation is exponentially dependent on the combustion temperature, cooled exhaust gas recirculation is associated with a significant reduction in NO_x emissions. Cooling the exhaust gas also improves cylinder filling and reduces thermal stress on the engine components.

With cooled exhaust gas recirculation, some of the exhaust gas is diverted upstream from the turbocharger turbine and routed to the exhaust gas cooler via an EGR valve. In the case of two stage cooling, **Figure 4**, the first cooling stage is high temperature cooling (HT EGRC), the cooling medium is the coolant from the main cooling circuit, and in the second cooling stage (low temperature stage,

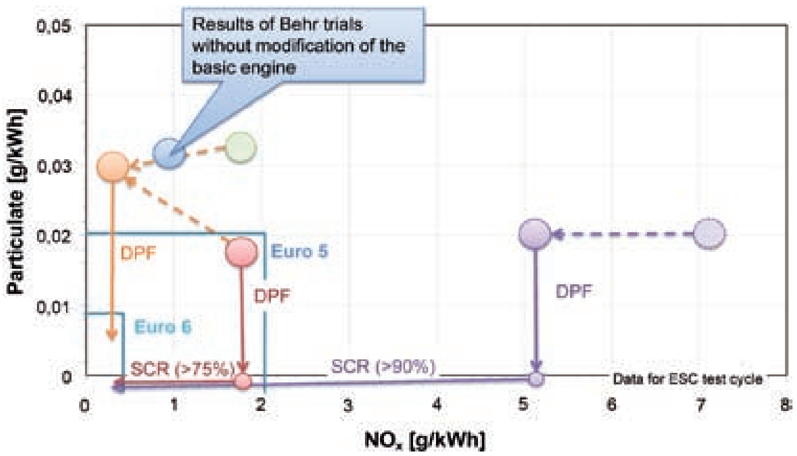


Figure 5: Potential of LT-EGR with respect to Euro 6

LT EGRC), it is the coolant from a low temperature circuit. To prevent the coolant from boiling in the first cooling stage, the exhaust gas and coolant flow in the same direction; the second stage operates in counterflow mode, which improves the cooling performance.

4.1.1 Self Cleaning of the EGR Cooler

A major advantage of two stage exhaust gas cooling – as compared with single stage cooling – is the self cleaning action of the EGR cooler and thus the stabilization of its cooling performance over the life of the cooler. This cleaning action is a consequence of the formation of condensation in the exhaust gas cooler. During the combustion, 1.26 kg of water for every 1 kg of diesel fuel is produced. Some of this steam condenses in the EGR cooler, where the condensation washes the deposits off the tubes of the cooler.

4.1.2 Cooling by Evaporation

Along with this self cleaning action, exhaust gas condensation also reduces the in-cylinder temperatures: firstly by the cooling effect from the evaporation of the charge air exhaust gas mixture and secondly by cooling due to evaporation of the intake air in the cylinder.

Cooling due to evaporation occurs when the condensate in the exhaust gas mixes with the dry charge air and evaporates. The heat required for this to happen comes from the charge air exhaust gas mixture, resulting in a fall in temperature of approximately 10 K. Because of the high dew point of steam, this cooling action occurs at high temperatures, for example 40 to 60 °C.

The exhaust gas condensate evaporates in the intake air but not completely: some water is remains and is conveyed with the intake air into the cylinders, where it evaporates in the compression phase. This second cooling effect limits the increase in the charge temperature during compression, lowering combustion temperatures and, therefore, NO_x emissions.

4.2 Two Stage Turbocharging with Intercooling

Cooling the charge air while keeping maximum cylinder pressures unchanged results in higher performance, lower fuel consumption and less formation of NO_x. In the LP and HP charge air coolers, Figure 4, the charge air, after being heated in each of the two compression stages, is cooled. The cooling of the charge air between the compressors, hence the term "intercooling", improves the efficiency of the second compressor.

4.3 Results

In various tests Behr together with AVL has already reduced NO_x values to about 0.8 g/kWh over the test cycle. However, the optimum has still not been reached. It might be possible to reach the Euro 6 limit, which is likely to be in the region of 0.7 to 0.4 g/kWh, **Figure 5**. It should, however, be noted that low temperature EGR is likely to be successful only in combination with two stage turbocharging and advanced fuel injection systems.

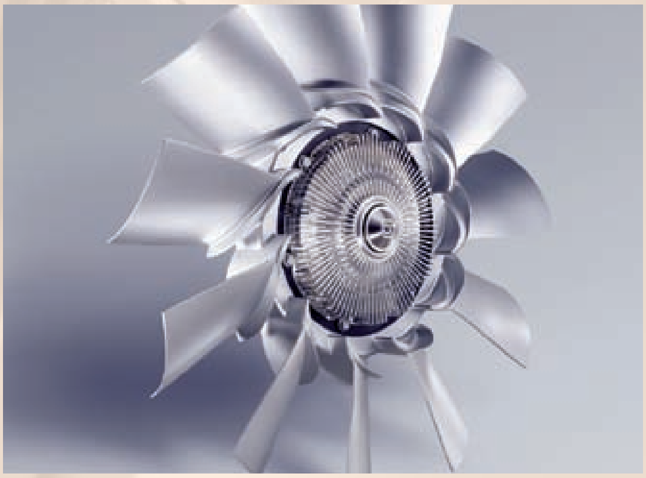
5 Conclusions

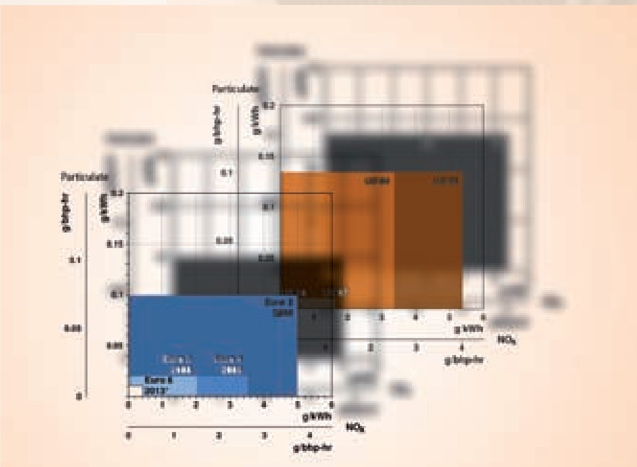
The Euro 6 and US '10 emissions limits are unlikely to be met using SCR technology alone. Cooled exhaust gas recirculation (EGR) will be part of the emissions solution. A combination of SCR and EGR is possible but may have weight, packaging, complexity and cost penalties.

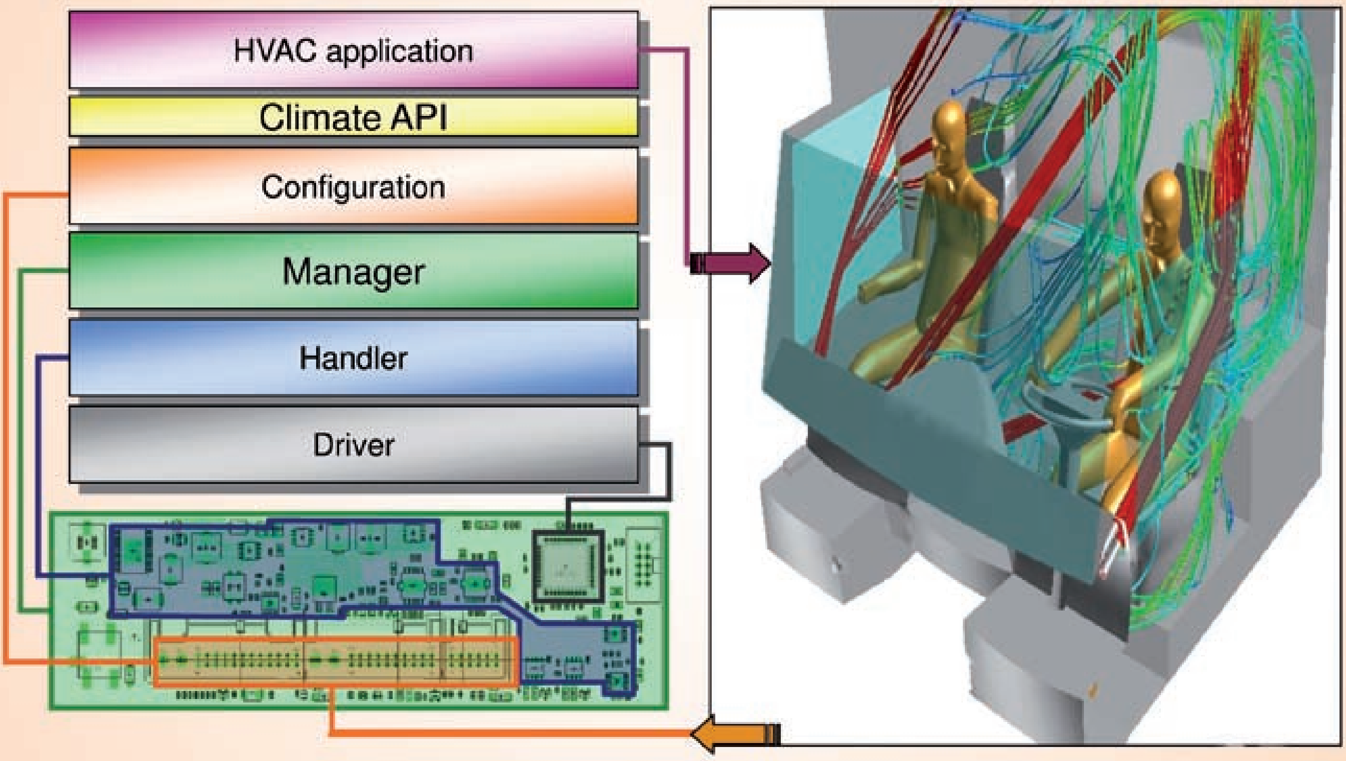
A possible solution is the two stage cooled exhaust gas recirculation process described above, combined with two stage turbocharging. This system possibly has the potential to achieve the potential Euro 6 limits. It should be noted that cooled EGR will also play a key role in enabling off-highway vehicles meet future emissions limits. ■

Special Behr

Thermal Management for Trucks







Ergonomics and Operating Concepts for Trucks

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort.

The Author

Ulrich Scheithauer is chief of product development Truckline/Thermomanagement at Behr-Hella Thermocontrol in Lippstadt (Germany).

1 Behr Hella Thermocontrol

Since the formation of BHTC as a 50/50 joint venture by the Behr and Hella groups in 1999, the company has grown rapidly and today is one of the world's leading manufacturers of control heads for HVAC systems. The product portfolio also includes control units (ECUs) for electric auxiliary heaters, blower controllers, and A/C sensors. The company counts the world's largest car and truck makers among its customers, and serves them not only from its parent plant in Lippstadt, but also from its subsidiary plants in North America, India, China, and, more recently, also in Japan. The BHTC mission is to provide "Comfort in Motion" by creating products that play a key role in ensuring optimum cimate comfort in cars and trucks.

2 Cars and Trucks: Differences in Climate Control

In recent years, there has been a sharp increase in comfort requirements for truck cabs. The driver's space is now recognized as a proper workplace. Ever more importance is accorded to the climate in the vehicle cab. Features that have long been standard in passenger cars have for some years now also been making their way into commercial vehicles. Today, no manufacturer can ignore its customers' demands for greater climate comfort. However, optimum climate comfort benefits not only the driver, but also all other road users as well: high interior air quality and a pleasant cab climate improve drivers' performance and help them to concentrate on the traffic.

Comfort is not only enjoying a pleasant climate in the driver's cab, but also the rapid response of the climate control system to changing climatic conditions. The system can thus ensure constantly mist-free windows and draft-free temperature control of the driver's workplace. The dash vents and the ventilation blowers are controlled in such a way that virtually no condensation forms on the windshield and side windows, and unwanted drafts are avoided.

Sensors measure the temperature at each of several points in the A/C system, and compensate for the influence of incoming solar radiation that falls directly onto the non-ventilated cabin temperature sensor. The climate control system can thus react quickly to changes.

Nevertheless, there are differences in the air conditioning of passenger cars and commercial vehicles that make the direct adoption of HVAC modules and control concepts from passenger cars impossible, Figure 1:

- A larger cab volume, and higher cabs.
- Commercial vehicles usually have a large, but vertical windshield. Compared with passenger cars, this results in less heat from solar radiation entering the cab in the middle of the day.
- Generally, the windows do not feature heat-absorbing glass comparable with that of passenger cars, and this results in a greater influx of heat when the sun is low.
- Cold outside temperatures, if they are not adequately compensated for by air conditioning, can result in an unpleasant flow of cold air at the windshield, leading to cold arms and thighs.
- Increased use as a result of ever denser traffic and frequent changes of drivers call for more user-friendly controls, that means it is important for the operator to quickly and intuitvely understand how the air conditioning system works.
- Owing to the greater movement range of the driver's seat, the operating controls must be larger and clearer in terms of their functional classification.
- The effect of the center air vent in the instrument panel is generally not so intense, owing to the greater distance to the driver.
- All system components must be designed for a longer service life.
- Today, some passenger cars have multi-zone climate control systems that must react more quickly to the changing amounts of incoming solar radiation due to the large sloping windows.
- Long-range trucks have a sleeper cab, which, in stationary operation, increasingly requires not only controllable heating, but also air conditioning; see the presentation on no-idle air conditioning.
- Passenger car platforms with high unit numbers of individual model series require specific climate control hardware and software components that are based on a standard module set. Control heads for truck air conditioning systems are also designed for platforms, but because the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software, Figure 2.

3 The New Climate Control System for the MAN TGX

For the design of the A/C control heads and ECUs for the air conditioning systems for the new MAN TGX, a modular concept was adopted from the outset. This concept makes a clear distinction between design and functionality.

The control head for the air conditioning system was thus integrated into the modern cockpit with significant space savings, and adapted to an individual design that meets demanding ergonomic and functional requirements. In all variants, mechanical Bowden cables from the control head to the HVAC system are dispensed with, and only six electric cables are used to connect the control head and ECU.

4 The HVAC Control Head

As the functionality of air conditioning systems increases, their operability often decreases. Especially in the case of commercial vehicles, owing to the long travel times with dense traffic, frequent changes of drivers, and the large movement range of the driver's seat, clearly identifiable and understandable controls are important.

We already provided an in-depth report on the link between operating ergo-

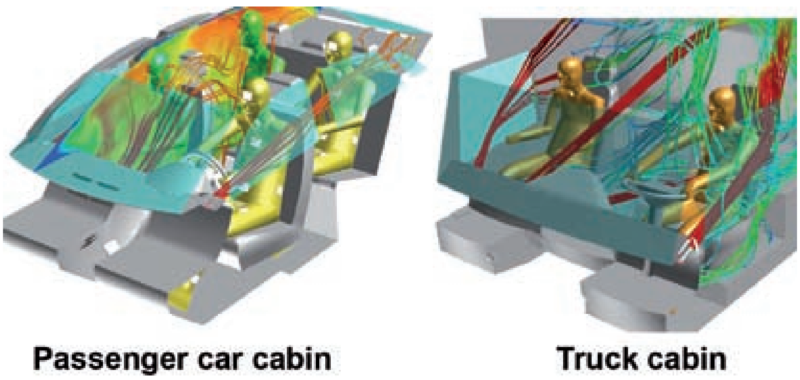


Figure 1: Cabin volume, layout and size of the windshield make up the big difference in the climate control between passenger cars and commercial vehicles

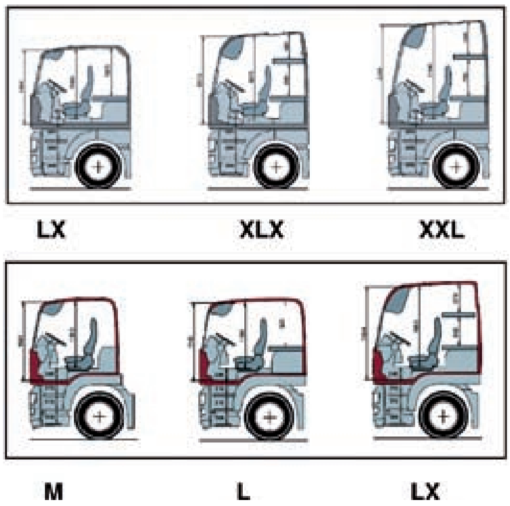


Figure 2: In commercial vehicles, the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software

nomics and traffic safety and a operability studiy carried out with the Technical University of Munich in 2007. Inadequate ergonomics lead to significant risks in traffic situations. The results show that easily recognizable symbols are based on:

- symbols/graphics
- depictions of people
- depictions of seats
- a vehicle contour to back up the symbols
- a combination of text and symbols.

Whereby symbols that are not easily recognized often contain text with no symbols, abstract symbols, or symbols that deviate from the international ISA standard.

The control heads for the MAN TGX therefore reflect the state of the art in relation to operating ergonomics, **Figure 3**.

In the fully automatic air conditioning unit, the driver selects both the desired air distribution and the blower speed by means of two control dials. The driver sets the temperature by means of two buttons, and the selected temperature is shown in a display. In the simpler heating variant, the temperature is set using the left-hand control dial, while the blower speed is changed by means of two buttons. In this A/C control head, particular importance was placed on easily understandable operation and ease of identification of the symbols for the switches and the display by both day and night. This is particularly important for trucks since they are driven for much longer periods, and also at night. It was therefore important to have highly contrasting images and clarity of symbols. This requirement was satisfied in all of the device variants by means of fail-safe LED lights, high-quality plastics technology for the operating buttons, and lasered symbols. In this way, with backlit symbols, no light can escape from the button control panel. Drivers receive an unambiguous acknowledgement from the system via the display in all control head variants, and can thus give their full attention to the traffic.

In the automatic mode of the fully automated system, the blower output temperature adjusts itself independently according to the vehicle's boundary conditions.

All the necessary settings for the air conditioning in the driver's cab and the sleeper cab in the new MAN TGX und TGS vehicles can be operated using a maximum of ten buttons and two control dials. One control head is therefore used to control both the driving and stationary operation. A second control head in the rear is therefore not necessary.

In order to ensure that the device has a long service life and is robust, and requires no maintenance, a non-ventilated interior temperature sensor (ITOS), **Figure 4**, was also used instead of the customary ventilated interior temperature sensor. The cab temperature is measured using the robust and maintenance-free sensor, and this is compensated for by means of a customized control system taking into account the incoming solar radiation, and also the heating of the device itself.

5 The Air Conditioning ECU

In the MAN TGX, a standardized air conditioning ECU was used for the first time. Behr and BHTC are thus responding to customers' demands for ever-smaller packaging dimensions of the control head and an individual design of the instrument panel with maximum control functionality.

For the climate control, a functional separation of the ECU and the A/C control head was selected, **Figure 5**. The heart of the ECU is a printed circuit board of modular construction and of standard dimensions. Thanks to the standard printed circuit board, the dimensions of

Figure 3: The control heads for the MAN TGX / TGL reflect the state of the art in relation to operating ergonomics

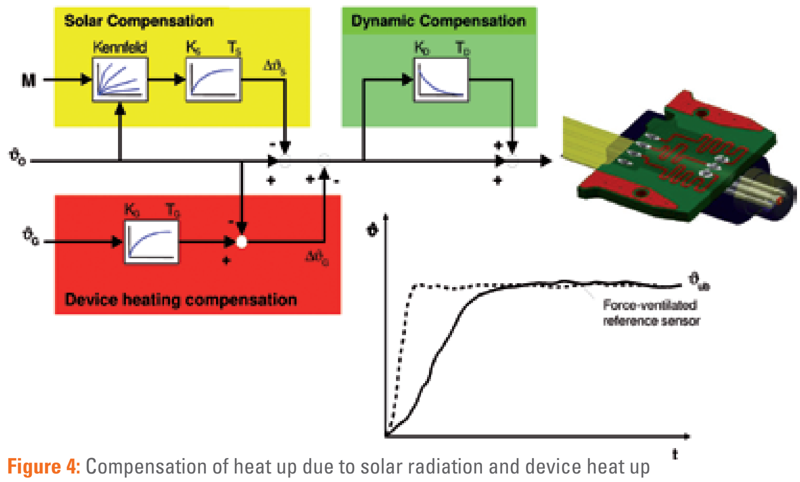


Figure 4: Compensation of heat up due to solar radiation and device heat up

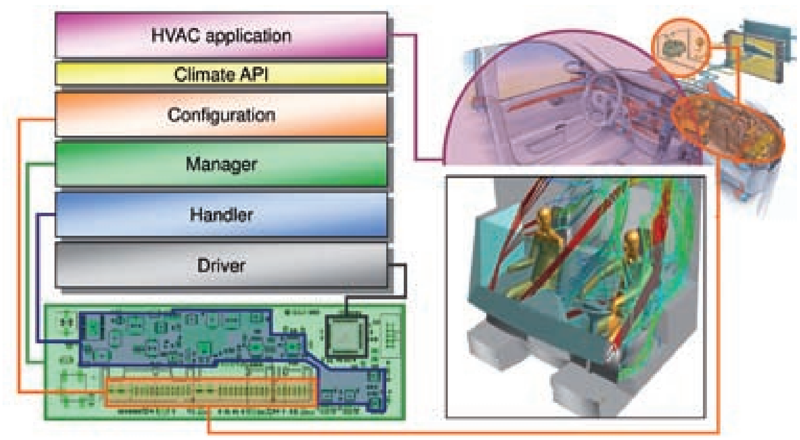


Figure 5: Architecture of the standardized air conditioning ECU – separation of function and design

the ECU and the connector plug are identical for all variants.

The ECU is installed in the vehicle in such a way that the HVAC module and ECU form a functional unit with short electrical connections. A mechanical coupling between the control head and the HVAC module is no longer required. In addition to the preferred mounting position on the HVAC module, other mounting locations in the vehicle are, in principle, also possible.

The open architecture and the less complex design of the control head give the customer more freedom in the design of the instrument panel in the vehicle than before, and better use is made of the existing space envelope. Other variants adapted to the customer's requirements can be obtained only by means of a different assembly and different programming of the processor. This reduces the development outlay required for variants, and cuts costs. The ECU is also flexible in terms of the interface to the customer's preferred data bus format.

6 Summary

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort. Operation of the air conditioning unit must respect ergonomic considerations, so that drivers take advantage of all of the capabilities of the A/C system on the one hand, and are not distracted from the traffic by its operation on the other.

With the unit's design and operating concept, BHTC has satisfied the increasing demands for an A/C control head that is modern, efficient, and at the same time user-friendly.

Whatever the initial climatic conditions at the start of the journey, or however they change during the trip, the climate control system always ensures consistently comfortable and draft-free air conditioning, and thus avoids any additional stress for the driver.

A climate control system that is functionally and ergonomically designed using state-of-the-art processes thus plays a key part in reducing the stress on drivers, and, thanks to the comfortable cab conditions, helps them stay relaxed in every traffic situation. ■

Non-idle Air Conditioning for Enhanced Road Safety and Reliability

The Author

Dr. Lubens Simon is chief of commercial vehicle climate systems development at the Behr GmbH & Co. KG in Stuttgart-Feuerbach (Germany).

Transportation of freight by truck is very important for the functioning of the economy and society. As the driving condition of the driver plays a key role in this, it is essential to provide adequate thermal and acoustic comfort during rest periods. A non-idle A/C system that provides air conditioning both during journeys as well as during rest periods and when the windows are closed, improves driver recuperation. The driver is thus better able to concentrate and feels fitter and more refreshed.

1 Introduction

Transportation of freight by truck plays a key role in the functioning of the economy and society in all Western countries. It is even more important that this transportation takes place in a safe, reliable, and eco-friendly manner, and that it is cost-efficient. Drivers play a key role in achieving this: their health, ability to perform and to concentrate, in short: their driving condition. In order to maintain this condition at a high level for the entire duration of the journey, drivers require a workplace that is ergonomically designed and has a pleasant cab climate.

This involves a high level of thermal and accoustic comfort, which is important not only during the journey itself, but also when any stops are made, whether they are voluntary or involuntary. The thermal comfort is particularly important in driver rest periods, because otherwise the degree of recuperation is reduced. This applies especially to the sleeping phase, since drivers who are not well-rested pose a danger to themselves and to other road users. The infamous "miscrosleep," one of the greatest causes of accidents, is primarily due to inadequate or unrestorative sleep. Non-idle air conditioning, that cools the cabin also during the rest periods with windows closed, enhances the thermal comfort of the driver and thus his ability to concentrate.

2 Driver Survey on the Use of Non-idle A/C Systems

In 2006, Behr surveyed 500 truck drivers from different countries with different vehicles at a total of six rest areas along Germany's main highways. The aim of the survey was to find out how the drivers use the cab as a living space, and what the requirements of this living space are (with a focus on air conditioning), and also what the future requirements of the market are, and which product strategy can be developed from this information.

After this general questioning, 16 drivers were selected for a longer interview. These people formed a representative market cross-section of long-distance drivers who had a non-idle A/C system.

It was found that the great majority of the drivers believe that a non-idle air conditioning unit is important. Around 90 % of the drivers who did not have this sort of system in their vehicle would choose to have one. Since only one fifth of all long-distance trucks are equipped with non-idle vehicle air conditioning, there is a very high market potential. By contrast: parking heating systems are found in all heavy-duty trucks. A summary of the driver's views: Non-idle air conditioning systems ...

- ... are used in a similar way as parking heaters, and are valued just as highly by drivers
- ... are nevertheless available commercially only at a market level of 20 %
- ... are perceived as improving drivers' personal safety
- ... avoid engine idling, and thus prevent fuel consumption and engine wear
- ... should provide air conditioning at night for up to ten hours, and for up to two hours during the day with incoming solar radiation
- ... should provide automatically controlled air conditioning for the entire cab
- ... should not require any servicing or any initial activation.

According to this information, non-idle air conditioning systems have a high market potential. From these and further results of the survey, the following specifications have been provided:

Non-idle air conditioning systems should ...

- ... cool the cab during overnight stops for up to ten hours and for up to two hours during the day (even with strong incoming solar radiation)
- ... provide draft-free cooling of the entire cab (not only the space above the bed)
- ... have automatic temperature control
- ... be reliable and easy to operate
- ... not require any maintenance; the charging of the energy storage devices (cooling battery or battery pack) should occur automatically
- ... be interfaceable with an automatic fresh air supply.

The requested hours of operation and performance can be fulfilled by electrical systems. Also, roof units will fulfill the expectations on non-idle a/c units. The non-idle air conditioning systems currently available on the market are still highly inadequate compared with what drivers want in terms of both their technology and their performance. In order to satisfy all of the requirements of the users, Behr has set itself the following additional design objectives for non-idle air conditioning systems:

- a low current draw in order to allow battery pack operation
- installation in existing roof openings for aftermarket applications
- satisfy truckmakers' installation requirements, specifically in terms of quality, durability and reliability and integration into the operating system architecture.

On the basis of these design objectives, an electric non-idle air conditioning unit

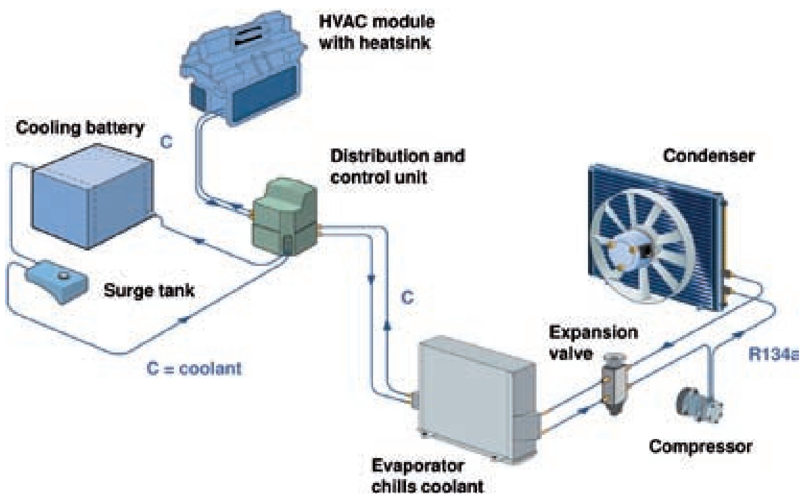


Figure 1: System diagram of the non-idle air conditioning with cooling battery from MAN

in the form of a roof unit was designed and constructed as a demonstration model, in addition to the non-idle air conditioning system with a cooling battery that is already in series production. Design of a rear wall unit is currently under way.

3 Technical Features of the Cooling Battery System

The non-idle air conditioning system with a cooling battery is fully integrated in the vehicle, and replaces the conventional engine-driven air conditioning system. The system has a secondary circuit **Figure 1**. In the charging phase, a conventionally operated refrigerant circuit intensely cools a liquid refrigerant in a special evaporator. This coolant, controlled by the distribution unit, cools both the heat sink in the HVAC module as well as the contents of the cooling battery, which therefore freezes. The heat sink replaces the conventional evaporator in the HVAC module; it cools the cab air during the journey, and during breaks in the journey. In the non-idle A/C system, the refrigerant circuit is in the resting state. By means of the circulating refrigerant, the heat from the vehicle cab is slowly transferred to the cooling battery, where the frozen content of the cooling battery is liquefied. The system with the cooling battery is fitted as standard in the heavy commercial MAN vehicles TGA (since 2003) and the more recent TGX from MAN (since 2007).

4 Technical Features of the Roof Air Conditioning Unit

This plug-in 24-V unit can either be factory fitted or retroffited on the aftermarket. The unit is made up of an electrically operated, conventional refrigerant circuit that essentially consists of a compressor, condenser with fan, receiver, blower, and evaporator with expansion device, **Figure 2**. These components are housed in a single module that projects into the roof opening of the vehicle. Inside the cab, a screen allows drivers to see only the air inlet and the air outlet openings, and the control head. **Figure 3** shows a cross-section through the roof unit installed in the ceiling of the cab, and how it works.

The unit is operated with recirculated air. Control of the fresh air supply is integrated in the control system of the engine-driven air conditioning unit. For the power supply, in addition to the starter batteries, an additional battery pack, for example consisting of lead-gel batteries, must be provided in the vehicle. Some of today's systems are, in fact, powered by conventional starter batteries, but these are not really suitable for operating non-idle air conditioning systems because they are designed to deliver a high current over a short period of time. The non-idle air conditioning system must, however, be supplied with power over several hours. In a nine-hour operation, the battery is almost completely drained, and thus needs to be recharged. If a starter battery was frequently charged and drained, its capacity would quickly be reduced even after 15 such cycles to under 40 %. Starter batteries are therefore unsuitable for this application.

Lead-gel batteries, by contrast, are cycle-proof, that means they can be repeatedly recharged to a high capacity.

The roof air conditioning unit provides sufficient power to air-condition the cab, even with incoming solar radiation during the day. The two-hours-per-day period of operation determined from the driver survey is not, however, the critical value for the battery pack, but instead night operation of up to ten hours. In the case of an average power consumption of the unit of only 400 W, this would require, for example, a battery pack with four standard size traction batteries. The low power consumption of 400 W is the result of the system's exceptionally high efficiency.

Figure 4 uses measured values from the Behr climatic wind tunnel to show the course of air conditioning at night

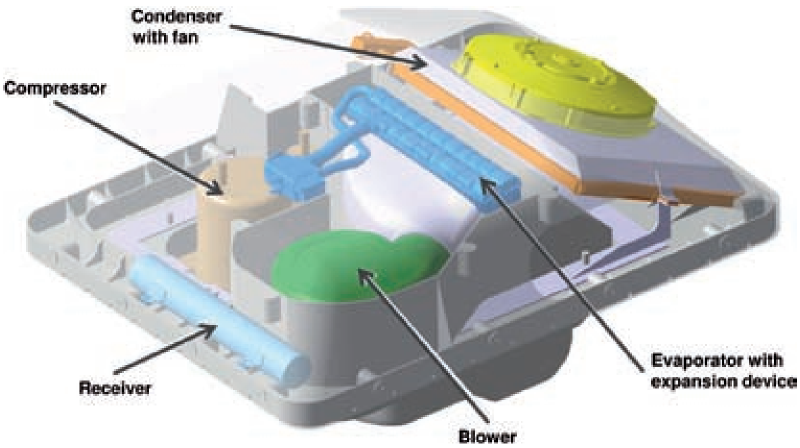


Figure 2: Schematic depiction of the electrial roof air conditioning unit

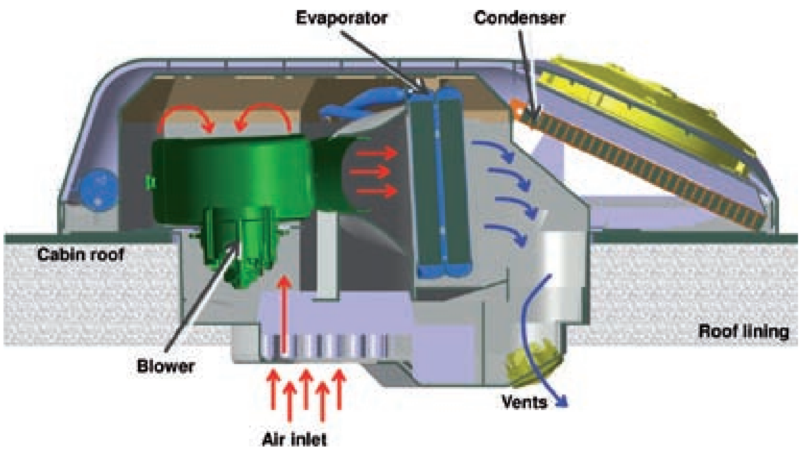


Figure 3: Side view of the electrial roof air conditioning unit

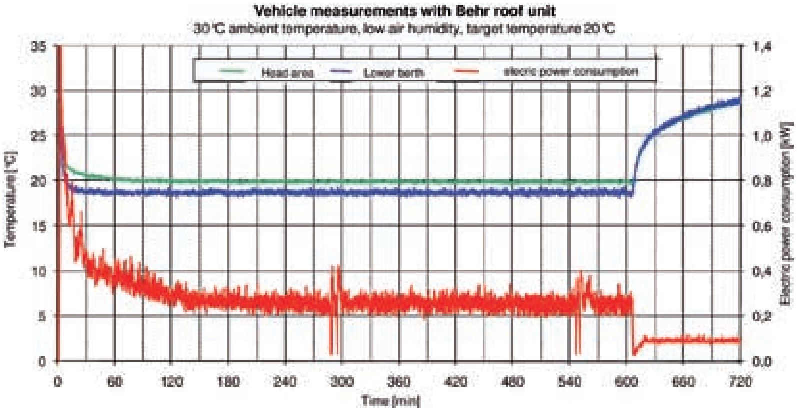


Figure 4: Cool down and power consumption of the electrial roof air conditioning unit at night

with an outside temperature of 30 °C. The target temperature of 20 °C is very quickly achieved and maintained, thanks to the temperature control over the ten hours. The power consumption is almost always less than 400 W.

5 Advantages of the Electrical System

The electrical system has two advantages over the system with the cooling battery: for one thing, drivers can access the cooling capacity at almost any time, because the batteries can store the power supplied by the generator for a long time. They therefore do not need to plan the charging or even to initiate it, since this happens automatically. During the journey, the battery pack is then constantly maintained in the fully charged state. In the system with the cooling battery, the charging of which is initiated manually, it is not possible to exclude the possibility that the driver may one day forget to initiate the charging, or may initiate it too late. If cooling is then required, there may be no or insufficient cooling capacity available. This point was also mentioned in the driver survey, which then also led to the call for an automatic charging of the cooling battery or battery pack.

The second advantage of the electrical system is that, with the battery pack for the non-idle air conditioning unit, additional electrical devices can also be operated, for example a television, computer, microwave oven, or coffee machine. Because the starter battery need not be used to do this, it therefore cannot be drained accidentally.

6 Behr's Development Capacity

As an original equipment manufacturer and systems supplier of passenger car and truck air conditioning units, Behr designs not only the HVAC modules, but also the control heads and associate software, working with joint venture companies such as Behr-Hella Thermocontrol (BHTC). This calls for expertise in the communication processes in the vehicle and for close collaboration with the vehicle manufacturers, for example for the construction of an interface between the engine-driven and non-idle air conditioning systems. Such an interface is required, for example, when the fresh air supply to the cab is to be taken over by the engine-powered A/C system instead of the non-idle air conditioning unit. This is particularly desirable when the truck's engine-driven A/C system is equipped with active carbon filters. In this case, the cab is supplied with filtered, gas-free air that increases drivers' safety when they are asleep. Generally, the fresh air is supplied at intervals, activated, for example, by a timer. The timed control saves battery power, but still guarantees an adequate supply of fresh air.

7 Summary

Non-idle air conditioning systems have considerable market potential, comparable with that of parking heaters, with which almost 100 % of long distance trucks are equipped. Behr's electrical units satisfy all relevant performance requirements, and have proven to provide a higher cooling capacity and higher efficiency than all comparable systems. A further advantage of the Behr units is their reliability, because the system components were designed specifically for use in trucks, and are sourced from series production of vehicle air conditioning units. ■

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US '10 envisages another drastic reduction in NO_x emissions for commercial vehicles.

Measures for Satisfying Future Exhaust Emissions Standards in Special-purpose Vehicles

1 Behr Industry

When Behr Industry was founded in 1990, the objective was to cater to special markets in the engine cooling and air conditioning sectors. The justification for this was that technical and legal requirements were made with respect to the components and systems of off-highway vehicles that were completely different from those for the passenger car and commercial vehicle markets – requirements that cannot be satisfied by simple modification of an existing component or of an existing system.

The split of Behr Industry and Behr GmbH & Co. KG essentially reflects our customer structure, since Behr's customers often operate in different market segments, and under different names. Today, Behr Industry is active in the markets for buses, heavy-duty engines, railway vehicles, aircraft, construction and agricultural vehicles, electronics, military products, and gensets (that means diesel-engine driven generators for generating electricity). The most important requirements are:

- The smaller production volumes or even single unit productions, also mean, that different development procedures, manufacturing technologies, and logistic concepts are necessary.
- The Euromot, EEV, and Tier X legislation governing emissions and CO_2

emissions is very similar to the Euro 5/6 and US 'XX standards from the car and truck vehicle sectors – only time-displaced by about three years.
– Other constraints on cooling requirements, installed position, and the available installation space.
– In the special-purpose vehicles, the components and systems are exposed to different stresses: fouling through mud, dust, and fibers results in different focuses for the development of heat exchangers. In some shipbuilding applications, cooling takes place using the seawater itself. The corrosive action of the saltwater is countered with special stainless steel.

2 Small-scale Series Production

For example for buses, small-scale series production specifically means annual volumes of approximately 500 to 3000 units. In the case of railway vehicles, the figure can be as low as just five to 100 units per year. Behr Industry must therefore use other processes for manufacturing radiators and coolers and for assembling complete cooling systems. Semi- or fully automatic production equipment can be used only rarely, and the costs of die-casting or functional plastic components often cannot be redeemed, owing to the high capital costs involved. Flexible systems are called for that require little or no capital expenditure; however, these demand higher manual production outlay and highly skilled manufacturing staff. Behr Industry also endeavors to carry over products or components from high-volume series production and integrate them (for example buses and tractors) in order to take advantage of the cost benefits of large-scale series production. This significantly reduces R&D expenditure, validation requirements, and the risk of failures in the field.

Behr Industry also employs the general Behr production standards and development tools and tests and develops its products in the test facility of the parent company, and uses the same simulation tools (FE analyses, CFD calculations, BISS). This makes the development of new products specifically catering to special market requirements efficient and competitive.

3 Exhaust Emissions Standards

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US 10 envisages another drastic reduction in NO_x emissions for commercial vehicles. The corresponding standard for the off-highway sector is Euromot stage IIIB / Tier IV A, and will come into effect approximately three years after Euro 5 / US 10. The limits for NO_x and particulate emissions are not much different from those of commercial vehicles: Euromot stage IIIB envisages a reduction of nitrogen oxide emissions to 2 g/kWh, and of particulate emissions to 0.025 g/kWh (Euro 5 specifies 2.0 NO_x and 0.2 PM).

The exhaust emissions standards for off-highway vehicles in the USA are similar. The standards that are similar to the US07 and US10 standards are the Tier 4a and Tier 4b standards, which will come into effect at the same time as Euromot stage IIIB, that means three years later.

In the bus market, we find a special situation; here, the EEV (Enhanced Environmental Friendly Vehicle) preliminary standard was introduced. EEV is not a mandatory limit, but rather a voluntary standard that is virtually no different from Euro 5 in terms of the limits on NO_x and particulate emissions. EEV engines essentially already satisfy the Euro 5 standard that will be in force from 2009. The environmental awareness of the bus operators, in particular in large cities, leads to their voluntarily complying with special limits as per EEV.

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In order to comply with the exhaust emissions regulations and to save fuel in off-highway applications, as in the case of commercial vehicles, systems such as cooled exhaust gas recirculation or two-stage turbocharging are used, **Figure 1**. Here, too, this similarly leads to increasingly complex cooling systems every time the exhaust emissions laws are tightened further. Higher charge air temperatures and pressures and quantities of heat in the coolant call for new solutions for heat exchanger design. The integration of cooled exhaust gas cooling and indirectly cooled charge air requires considerable systems expertise in order to be able to guarantee the necessary cooling within the special constraints of the off-highway market.

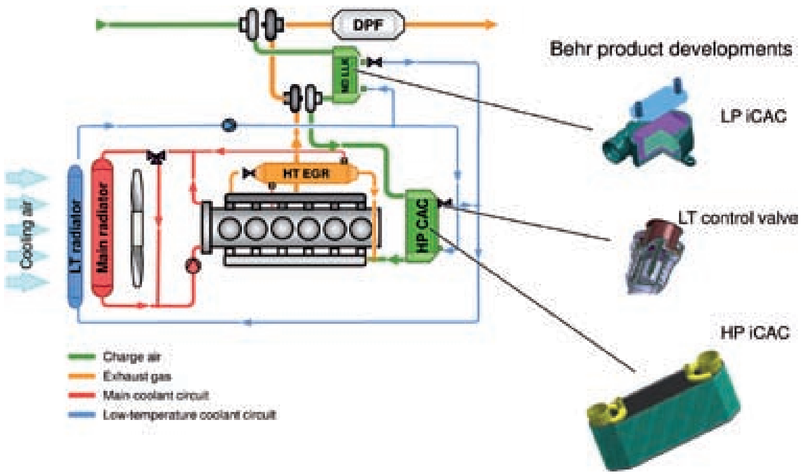

Figure 1: Schematic representation of a two stage turbocharging with indirekt charge air cooling

4 Fouling

A distinctive feature of special-purpose vehicles is their use in very different areas of application: mines, fields, rails, water, construction sites, forests, or garbage dumps. Fouling on the external surface through which cooling air passes thus takes very different forms. Sand, dust, oils, pollen, leaves, plant debris, grass, litter, and many other soiling agents in every possible combination accumulate on the air side inside the radiator and between the fins, Figure 2. This leads to a higher air-side pressure loss and restricts the flow of cooling air. The radiator can no longer provide the desired cooling power to the engine, and engine performance decreases accordingly.

Here, conventional radiators with louvered corrugated fins cannot be used. Behr Industry has developed special cooling air fins specifically for these applications. Unlike conventional fins, these do not have any louvered structure on their surface; instead, they are flat or corrugated. In car or truck radiators, these louvers serve to improve heat transfer between the cooling air and the cooling water, because the air does not pass through the fins in a laminar flow, but instead turbulence is produced on the louvers, Figure 3. However, a lot of dirt particles collect on these louvers that cannot be removed by using compressed air, for example. If there are no louvers, dirt particles can be blown away against the direction of flow.

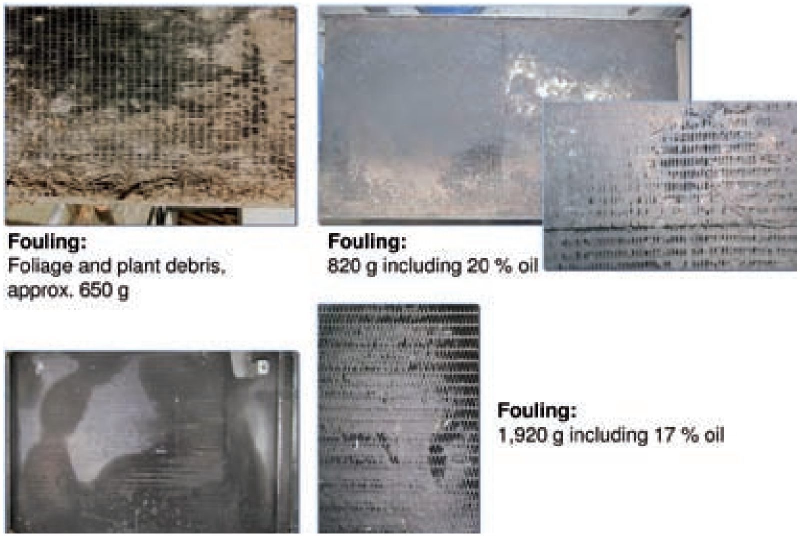

Figure 2: Representative examples of different foulings as found in off-highway applications

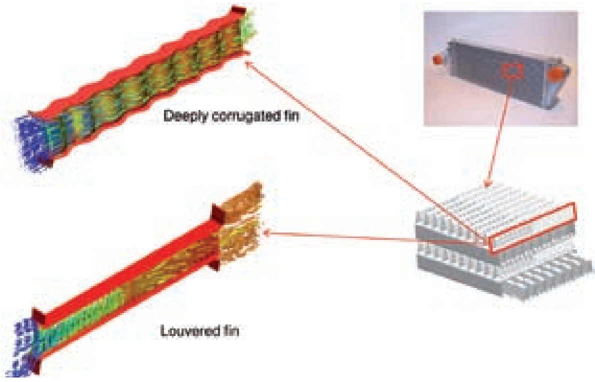

Figure 3: Comparison of a deeply corrugated fin and a louvered fin

In order to understand the mechanisms of fouling and to draw the appropriate technical conclusions, Behr Industry has been working closely with a number of institutes for several years. Figure 4 and Figure 5 show the results of tests on different cooling air fins that were realized in collaboration with the ILK Dresden (Institute of Air Handling and Refrigeration Technology in Dresden). These tests investigated to what extent the pressure drop on the cooling air side is dependent on the dust concentration and the fin used. It was found that the flat fin has the smallest pressure drop. Figure 5 shows the results of similar tests, but under more realistic conditions using fibers as the fouling agent. A flat fin, a staggered fin and a louvered fin were exposed to fibers during usage and the cooling air side pressure drop was measured over time. After a predetermined cycle had been completed, the fins were cleaned with compressed air. It is observed that the pressure drop in the louvered fin is worse after every cleaning cycle compared with the flat fin and the fin with deep corrugations. This is because fibers penetrate deep inside the fins, and, in the louvered fin in particular, can then no longer be removed. Therefore, over time, the radiator with the louvered fins becomes clogged up, and can no longer be cleaned.

Of course, the efficiency of the radiator decreases with the soiling of the louvers. Together with our customers, we must therefore arrive at a compromise between the prevention of fouling and the performance density of the radiator.

Furthermore, the arrangement of the individual coolers (radiator, charge air cooler, etc.) can play a role in minimizing the susceptibility of the cooling module to fouling. In conventional radiators, the individual radiators are arranged one behind the other ("face to face"). The problem here is that dirt particles may pass through the first radiator and become caught in the second one. For cleaning, the cooling module would have to be dismantled. To avoid this, the radiators can be arranged next to one another ("side by side"), so that all of the faces can be cleaned from the outside. Alternatively, the frame of the cooling module can also be designed to swing open, in order to facilitate cleansing of the second radiator, Figure 6.

5 Systems Expertise

All of these requirements must be implemented for a small market that individually caters to specific customers. Behr Industry provides not just the coolers and

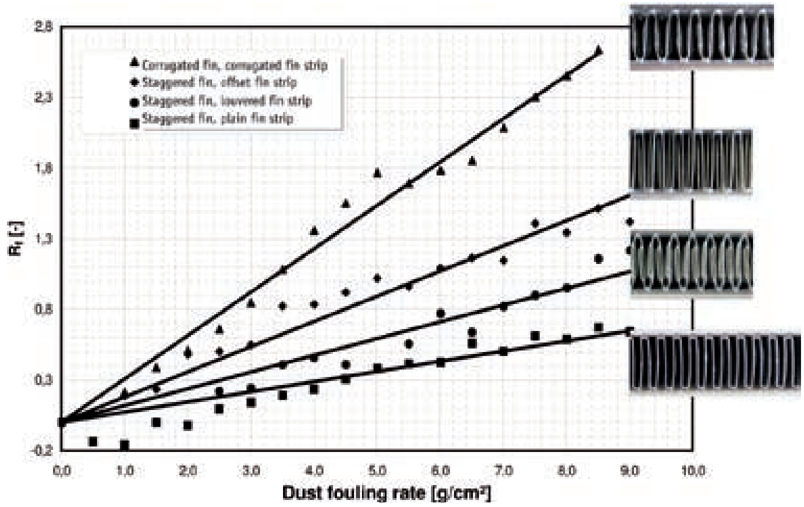

Figure 4: Fouling: Impact of dust on the pressure loss in coolers. Investigations performed by ILK Dresden on behalf of Behr Industry

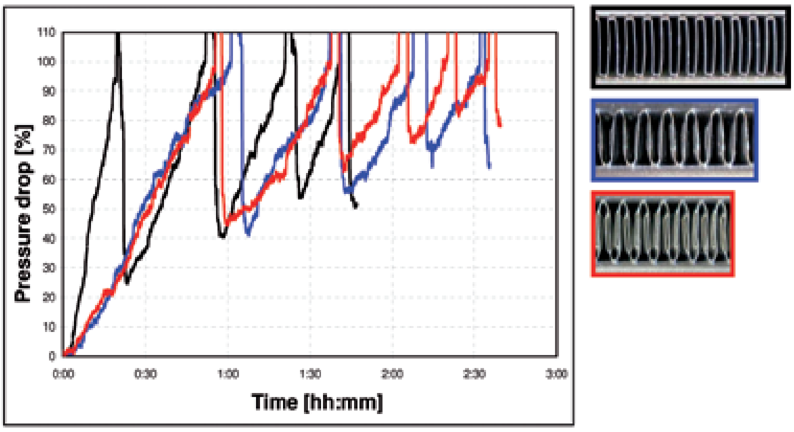

Figure 5: Fouling: Impact of fibers on the pressure loss in coolers and the regeneration of coolers with different fins. Investigations performed by ILK Dresden on behalf of Behr Industry

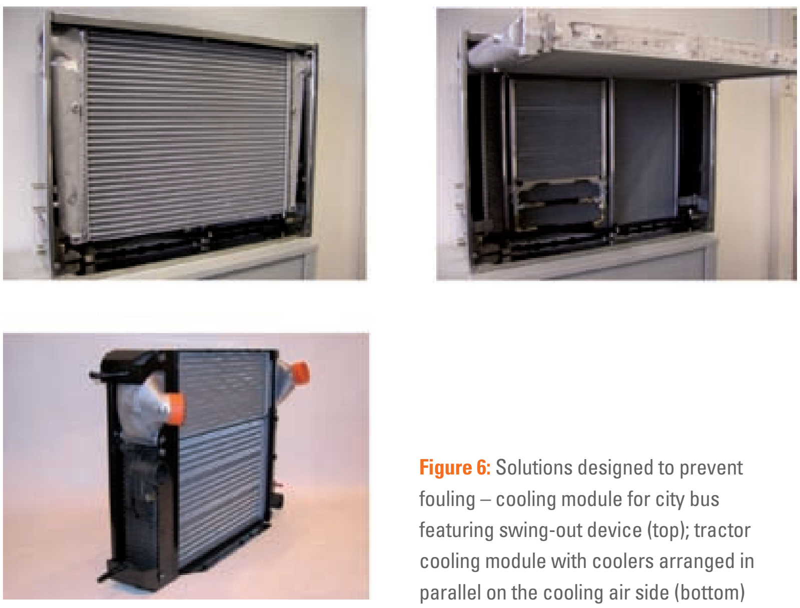

Figure 6: Solutions designed to prevent fouling – cooling module for city bus featuring swing-out device (top); tractor cooling module with coolers arranged in parallel on the cooling air side (bottom)

radiators themselves, but also complete ready-to-install cooling systems including the radiator/coolers, fan, fan drive, frame, and, if required, also the surge tank, water and oil pumps, and level controller, working in close collaboration with and for its customers.

When solving these technological problems, Behr Industry calls on Behr‘s development methods, results and products, as they are described in the article “Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles”. Behr Industry uses this technology and adapts it to suit the respective engines and the needs of the different special markets. Indirect charge air cooling is standard in commercial vehicle engines. The corresponding indirect charge air coolers are designed in a stacked plate construction. Behr Industry adapts the coolers for a potentially higher engine power. This can be achieved with a simple scaling, that means an increase in the quantity of stacked plates, for example, or, alternatively, by means of bundling existing EGR coolers when there are very high quantities of exhaust gas in the cooled exhaust gas recirculation, for example.

Because the installation position of the engines in special-purpose vehicles is often different from that of conventional commercial vehicles, adapting the components for the new installation position represents another challenge.

If the installation position changes, very often the air ducting on the cooling module or the position of the surge tank relative to the radiator changes as well. In conventional applications, the cooling air is routed from the front through the radiator into the engine compartment. In railway vehicle applications, for example, this is often not possible, owing to the installation position. In roof units, the air is conveyed laterally through the radiator and leaves the module at the top. In other locomotive applications, the radiators are located at the bottom of the module and the cooling air is routed through the assembly from the top to the bottom. If the surge tank for the cooling medium cannot be mounted above the radiator, technical solutions such as an anti-cavitation tank or two-chamber system must be found in order to ensure that the cooling circuit remains free of air. ■

In recent years Behr has made such progress in developing cooled exhaust gas recirculation and iCAC systems that commercial vehicle manufacturers now have at their disposal reliable, production-ready solutions for reducing NO_x emissions. When used in combination, these new cooling systems can meet Euro 5 emissions requirements without the need for a special exhaust treatment process such as selective catalytic reduction (SCR).

Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles

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1 Introduction

And in contrast to SCR, these innovations do not require any additional operating agent. When they are used in conjunction with the latest engine and injection technology there is no increase in fuel consumption, and they also allow weight reductions at comparable costs. Further benefits are the flexibility of application of these new solutions, and their high potential for further development to meet Euro 6 requirements.

2 Emissions Standards and Reduction Technologies

2.1 Emissions Standards

Since 1992 (Euro 1), the limits for heavy trucks have been brought down in five stages, including some very drastic reductions. Since 2000 (Euro 3) emission limits for NO_x have been reduced from 5 to 2 g/kWh, and particulate emissions from 0.10 to 0.02 g/kWh. In percentage terms this corresponds to a 60 % reduction for NO_x and 80 % for particulates.

2.2 Exhaust Air Cooling and Charging

The exhaust gas recirculation process is essentially based on the fact that the exhaust gas has a higher heat capacity and a lower oxygen content than air. This causes the combustion temperatures in the cylinder to fall. The cooling of the exhaust gas and the charge air makes the temperatures drop even further. Because NO_x formation is an exponential function of these temperatures, a combination of cooled exhaust gas recirculation and turbocharging with CAC was able to meet the Euro 4 limits. Compliance with the stricter requirements of Euro 5 requires either an increase in EGR rates or a reduction in exhaust gas and charge air temperatures. The single stage EGR with two stage turbocharging plus intercooling, and two stage cooled EGR with single stage turbocharging are available for this purpose.

3 Engine Cooling Systems for Euro 5

Over the last few years Behr has been investigating how the increasingly stringent limits can be met by improving engine cooling. In particular, efficient charge air and exhaust gas cooling have a positive effect both on NO_x formation in the combustion chamber and fuel consumption. The newly developed production-ready engine cooling systems for Euro 5 and their components are described below, including comparisons with the SCR system.

3.1 Engine Cooling System with Single Stage Exhaust Gas Cooling and Two Stage Turbocharging

Figure 1 is a functional schematic of such a cooling system. It comprises an exhaust gas cooler which is cooled by the engine coolant, and a low temperature (LT) cooling circuit which contains two charge air coolers and a low-temperature radiator. Since the LT-radiator has a large frontal area and is the first cooler to be exposed to the cooling air flow, very low charge air temperatures can be obtained. This type of CAC is called indirect CAC.

In the EGR cooler, **Figure 2**, the exhaust flow component for recirculation, removed from the engine at the exhaust manifold, is cooled and then added to the charge air upstream of the intake manifold. This causes the temperature of all the intake air to be lowered, which reduces the production of NO_x. However, single stage EGR cooling as used for Euro 4 is not sufficient for Euro 5; this requires either more intensive cooling or an increased EGR rate. For the latter, in order to provide a sufficient oxygen concentration in the cylinder, it is necessary to have a higher charge pressure, which in this system is obtained using two stage turbocharging with intercooling. Two stage turbocharging enables a constant engine output to be maintained in spite of increased EGR rates, and prevents any increase in particulate emissions.

In both charge air coolers the charge air, which undergoes intense heating in each of the two compression stages, is cooled back down and some of the heat which was absorbed is transferred to the liquid coolant. In the LT-radiator this heat is then dissipated into the ambient air. This radiator is installed in the vehicle frontend, which in today's truck diesel engines is the normal location for the conventional charge air cooler, connected to the turbocharger and to the intake manifold of the engine via bulky air ducts. These ducts can be eliminated with indirect CAC, which saves space and simplifies packaging.

The indirect charge air cooler can have a very compact design thanks to its high level of efficiency (compared to a charge air-to-air cooler), and this makes it possible to place the cooler between the turbocharger and the intake manifold. This also means that the charge air ducts do not need to be diverted. The charge air pressure loss can thus be reduced by up to 50 % and the charging pressure can be increased accordingly, which both improves cylinder air filling and simplifies the gas exchange process. Both factors reduce the fuel consumption at a given output.

Dispensing with the air ducts also reduces the air volume in the system. In a 12-l diesel engine a reduction of the air volume of more than 50 % was achieved thanks to iCAC. As a result the system reacts more quickly to load changes. Unlike the situation in passenger cars, however, in commercial vehicles it is not a matter of rapidly increasing torque, but of preventing emissions, for example particulate emissions. The well-known cloud which a truck without a particulate filter produces when the driver suddenly accelerates, happens because the turbocharger cannot supply the amount of air required for full-load operation straight away. There is then not enough oxygen for full combustion of the fuel, and particulate formation briefly increases rapidly. The smaller air volume thus reduces particulate emissions into the environment or the charge build-up on the particulate filter.

The intercooling of the charge air has a positive effect on the efficiency of the second charger. The charging pressure, which today involves pressures of up to 3.6 bar in the case of single stage turbocharging, can reach values of 4 to 5 bar absolute with two stage turbocharging and intercooling. As already described,

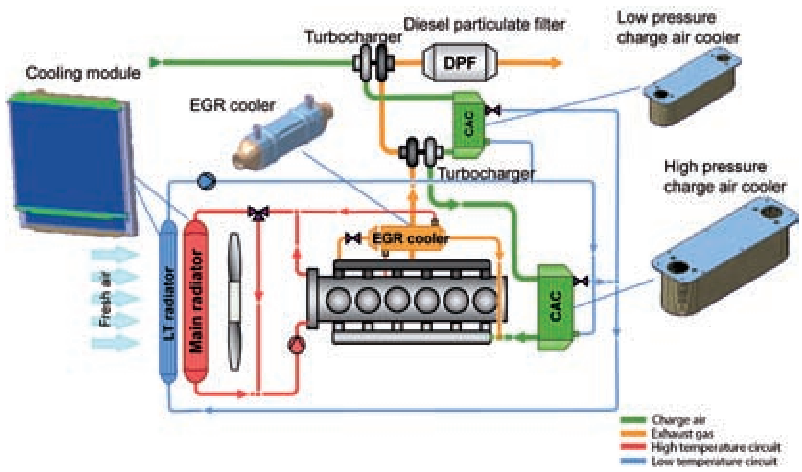


Figure 1: Engine cooling system with single stage EGR cooling and two stage turbocharging

this makes it possible to increase the EGR rates without reducing performance or increasing particulate emissions. Furthermore, a higher charging pressure theoretically opens up the following optimization opportunities:

- Increase in the power density (power per unit of displacement) of the engine. This leads either to increased engine output for the same displacement or smaller displacement for the same engine output ("downsizing"). The latter in particular has a positive effect on fuel consumption due to reduced friction in the engine.
- Increase in the excess air in the cylinder. Owing to the higher oxygen concentration in the cylinder this has a positive effect on soot formation. In other words the fuel is almost completely burned up, and less particulate matter is produced.

3.2 Engine Cooling System with Two Stage Exhaust Gas Cooling and Single Stage Turbocharging

In this system, **Figure 3**, the exhaust gas to be recirculated is first fed to an exhaust gas cooler which is cooled by the engine coolant. It is then routed to a second cooler which, as shown in the functional diagram, is located next to the charge air cooler. In this cooler the exhaust air is cooled by the ambient air. The air flow required for this is produced by the fan and/or by the airflow past the vehicle, according to the travelling speed.

Since the exhaust air is cooled in two stages in this system, resulting in lower exhaust gas temperatures, single stage turbocharging with CAC is sufficient to meet Euro 5 requirements. The charge air is cooled by the ambient air as in a conventional charge air cooler. This is why it is installed at the front of the vehicle where the ambient air flows through it. In this cooling system the exhaust gas and charge air can be brought to approximately the same temperature levels, which significantly lowers the mixing temperature upstream of the Intake manifold. In contrast to the shown separate arrangement of the charge air cooler and exhaust air cooler, this is an integrated cooler, that means a single unit comprising the charge air cooler and the exhaust air cooler.

4 Product Innovations

4.1 Integrated Exhaust Gas Cooler and Charge Air Cooler

The system consists of series-connected individual exhaust gas coolers, **Figure 4**, operating with different cooling media: engine coolant and ambient air. The air-cooled EGR cooler is integrated into the charge air cooler. This form of integration is the first of its kind worldwide.

The exhaust air cooling process: the exhaust gas flows from the cylinders are brought together in the exhaust manifold. From there some of the exhaust flows into the exhaust gas (top right, Figure 4). In this first stage of exhaust gas cooling the exhaust gas is cooled by the engine coolant. This part of the exhaust flow is then conveyed to the second stage, the air-cooled EGR cooler, integrated into the top area of the charge air cooler. When ambient air temperatures are low, the air-cooled exhaust gas cooler can be circumvented by means of a bypass in order to prevent the cooler from freezing. In both cases the exhaust gas then enters the intake manifold and the individual cylinders. It has first been mixed with the charge air cooled in the charge air cooler, so that the intake air has a uniform composition and temperature, which is important for ensuring the same combustion process in all cylinders.

In the first stage of exhaust gas cooling the exhaust gas temperature is reduced to 200 to 150 °C. In the second stage, the low temperature stage, it is then reduced to 25 to 20 K above the ambient air temperature. This lowers the temperature of the intake air overall, based on the mix ratio of charge air and exhaust gas.

The core of the air-cooled EGR cooler consists of tubes conveying exhaust gas and corrugated fins lying between them. In this cooler too, the tubes have been stamped inside to form turbulence-generating winglets.

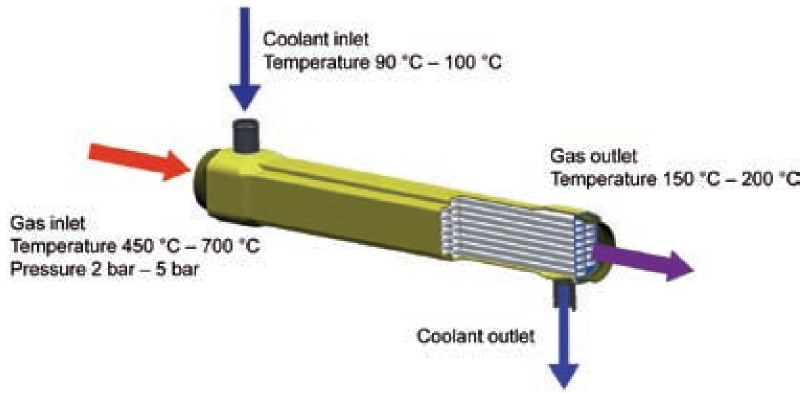


Figure 2: EGR cooler

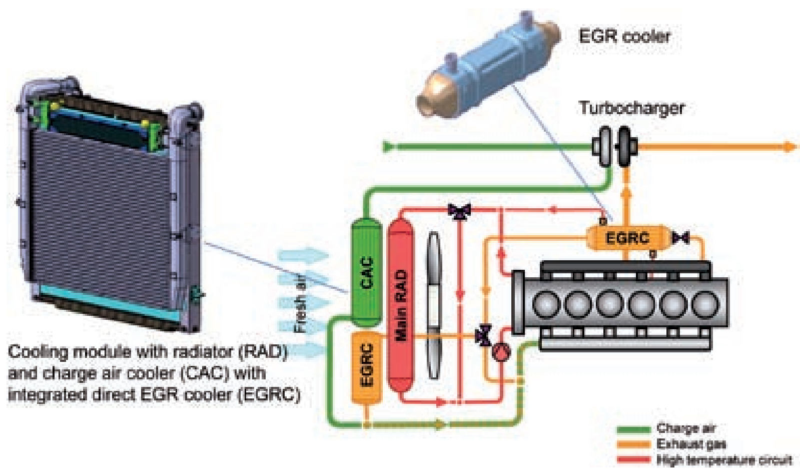


Figure 3: Engine cooling system with two stage EGR cooling and single stage turbocharging

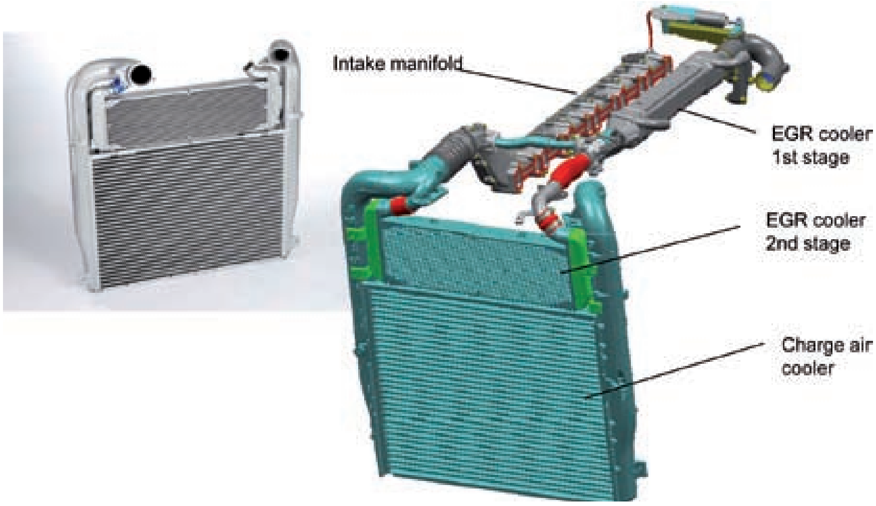


Figure 4: Two-stage EGR cooling: 1st stage coolant cooling, 2nd stage air cooling. EGR cooler integrated in charge air cooler

Figure 5: NFX 750 fan with ERS 250 fan drive

The tubes and corrugated fins are bonded together in a brazing process whereas the pipes and exhaust gas tanks are welded. The cooler consists of corrosion-resistant stainless steel tubes and corrugated fins and the exhaust gas tanks are also made of stainless steel. Features of the integrated charge air/exhaust air cooler module:

- optimized loss of pressure in exhaust gas and charge air cooler
- good mixing of charge air and exhaust gas at the mixing point
- bypass prevents freezing of the exhaust gas cooler
- no return flow of condensate into the charge air cooler
- EGR cooler is corrosion resistant.

4.2 iCAC with Integrated Thermostat

The higher EGR rates for Euro 5 compared to Euro 4 also necessitate higher charging pressures, leading to an increase in the charge air temperature. The charge air coolers used must therefore be able to withstand temperatures of more than 220 °C and pressures up to 5.1 bar absolute. Changes to the design of the charge air cooler can reduce the level of stress, which is based on the pressure and temperature load, to such an extent that the coolers are able to withstand the higher loads.

This aspect was taken into account from the outset for development work on the indirect charge air coolers and, as in the case of the charge air/EGR cooler module, development results were checked with stress analyses using the finite element method (FEM). The indirect charge air cooler is a stacked plate system comprising plates for the charge air and the cooling water ducts. Between the plates there are turbulators for the charge air and the coolant, which are optimized for heat transfer and temperature and pressure requirements.

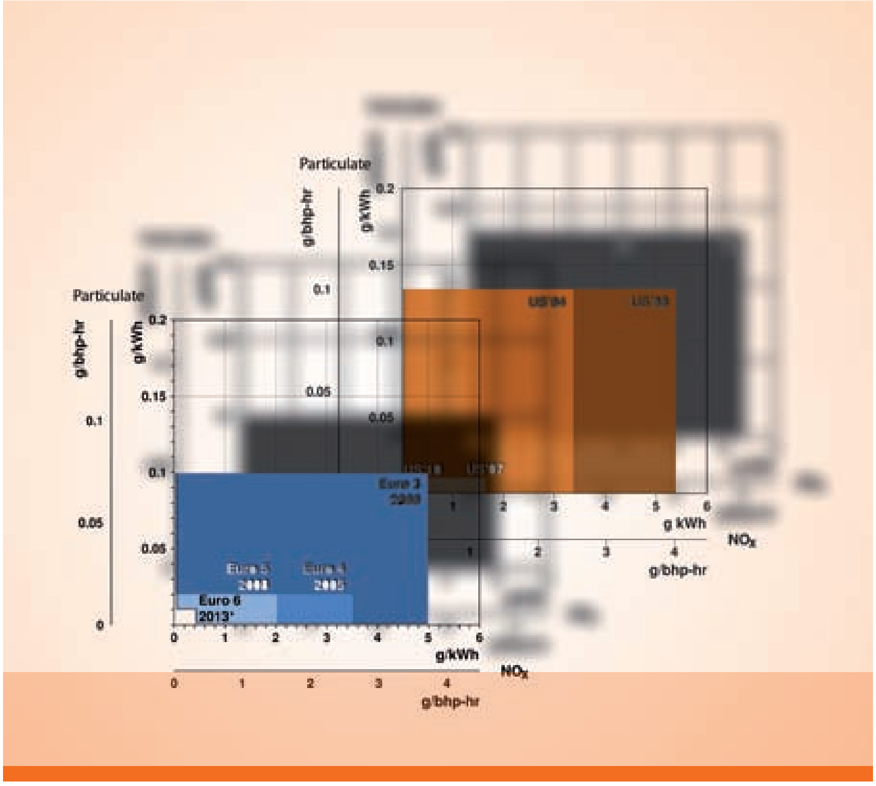
The charge air cooler is operated in a counterflow arrangement, that means the hot charge air flows in on one side and is cooled with cooling water flowing in the opposite direction. It was decided to use two intake ducts for coolant distribution. The coolant flow rate is controlled by means of temperature-controlled choke thermostats at the coolant outlet of the charge air cooler. According to the heat input from the hot charge air, the coolant flow rate is very quickly adjusted by means of fast-responding wax elements, thus avoiding the need for a complex control system.

4.3 Fan and Fan Drive

Fan output has been improved with the new NFX 750 fan, **Figure 5**. The modified blade geometry and higher number of blades (increased from eight to eleven) has boosted fan output while retaining almost the same axial construction depth as in the current series-produced model. The higher fan efficiency has also allowed the drive power to be reduced by approximately 10 % for the same mass air flow. The fan is driven by the Visco ERS 250 fan clutch. This electronically controllable clutch can transfer 40 % more torque than currently used fan drives with comparable size, along with significant improvements in controllability and dynamic clutch response. This means even more precise fan activation than before in response to the actual cooling demand, allowing the complete elimination of superfluous fan noise.

In order to cool the Visco fan drive sufficiently to accommodate its high operating range, the fan hub design has been optimally adapted to the clutch. Flow dividers and flow stabilizers in the region of the fan hub ensure that the inflowing cool air is conveyed through the cooling fins of the clutch and can then flow unobstructed through the fan blades. The result is improved cooling of the silicone fluid in the clutch and a higher slip power tolerance. Another effective means of protecting the silicone fluid in the clutch from overheating is continuous simulation of the silicone fluid temperature in the engine control unit.

The NO_x and particulate matter emission limits at Euro 5 and US 2007 (abbreviated as US '07) for commercial vehicle engines are a major challenge for engine and exhaust gas aftertreatment technology. US '07 is already in effect; Euro 5 will come into force in October 2008. Even more demanding technological challenges are to come: from January 2010, US 2010 (US '10) limits will apply in the USA, and the introduction of Euro 6 is expected in 2013. However, the commercial vehicle engines, which will have to meet those limits are being designed now. Behr's low temperature exhaust gas recirculation provides an appropriate technology for these engines.



NO_x Reduction Potential of Cooled Exhaust Gas Recirculation in Euro 6 Commercial Vehicles

The Author

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1 NO_x and Particulate Limits

The Table (top) shows how far the limits have reduced from Euro 3. The Euro 6 values are still to be finalized but will involve drastic reductions: in the case of nitrogen oxides (NO_x) probably by more than 80 % (from 2.0 to 0.4 to 0.7 g/kWh) and for particulate matters (PM) by more than 50 % (from 0.02 to less than 0.01 g/kWh). In the USA the forthcoming US '10 limits for NO_x are 0.20 g/bhph (approximately 0.27 g/kWh) and for PM 0.01 g/bhph (approximately 0.0134 g/kWh), Table (bottom). Of course the new limits should be met with the minimum fuel consumption penalty.

2 From Euro 5 to Euro 6

A very important step towards reducing NO_x and particulates in recent years has been the further development of the combustion system. Optimized combustion chambers, improved fuel injection

and turbocharging with charge air cooling meant that it was possible for commercial vehicle engines to comply with the Euro 3 NO_x limits without any special exhaust gas aftertreatment. However, by the time Euro 4 came into being these techniques were, for the most part, no longer sufficient. To meet the new standards additional measures were required.

In terms of internal engine measures, however, it is not possible to minimize both NO_x and PM emissions at the same time (the NO_x/PM trade-off). A viable method of achieving this goal is to minimize one component inside the engine, for example NO_x, and the other outside the engine: in this case the particulates, using a particulate filer. Conversely, reducing particulates by measures inside the engine means that NO_x reduction has to take place downstream of the engine, for example by means of the process of selective catalytic reduction, SCR.

Behr worked together with engineering consultant AVL to investigate the NO_x reduction potential of SCR and cooled exhaust gas recirculation (EGR) technology. The findings indicate that both SCR and cooled EGR are viable options for Euro 5, **Figure 1**.

Euro 6 will require enhancements to the Euro 5 technology, as illustrated in **Figure 2**. Possible concepts are:

- SCR: Selective catalytic reduction, normally combined with single stage charge air cooling.
- EGR: Cooled exhaust gas recirculation combined with two stage turbocharging with intercooling. The exhaust gas cooling also takes place in two stages: a 1st stage of high temperature exhaust gas cooling (HT-EGR), and a 2nd stage of low temperature exhaust gas cooling (LT-EGR).
- SCR plus EGR: combinations of SCR technology and cooled exhaust gas recirculation are also possible. Boosting takes place in a single stage and exhaust gas cooling is a two stage process with high and low temperature stages (HT and LT stages). Other combinations are also possible. However, the common feature in all of these is that they are complex, expensive and require considerable space.

All systems require a diesel particulate filter (DPF) to reduce PM emissions.

3 Selective Catalytic Reduction

The SCR technology already used in Euro 4 and Euro 5 systems for commercial vehicles is based on the addition of urea in the form of an aqueous solution (Adblue) to the exhaust gas flow. Hydrolysis of the urea produces ammonia, a NO_x reducing agent which converts the NO_x into steam and nitrogen in a special catalytic converter. The complete exhaust gas aftertreatment system in this case consists of a diesel oxidation catalytic converter (DOC), a DPF, a hydrolysis catalytic converter (HC), a SCR catalytic converter (SCR cat) and trap catalytic converter (TC), and the Adblue tank and a metering unit.

However, the extremely low Euro 6 and US '10 limits probably cannot be met with catalytic NO_x reduction alone. This is because of the new test cycles for measuring the emissions. Instead of the ETC (European Transient Cycle) currently specified, for Euro 6 it is likely that the new WHTC (World Harmonized Transient Cycle) will be used. This cycle results in lower engine speed and load overall and, therefore, lower exhaust gas temperatures.

However, low exhaust gas temperatures reduce the generation of ammonia from the urea solution. Additionally, at low temperatures the catalytic converter also loses some of its efficiency. Thus the

Table: NO_x and particulate emission limits for heavy duty trucks (> 3.5 t) for Europe (top) and the USA (bottom)

Phase	Introduction date	NO_x [g/kWh]	Particulate [g/kWh]	Test cycle
Euro 3	October 2000	5.0	0.10 (0.16)	ESC (ETC), ELR
Euro 4	October 2005	3.5	0.02 (0.03)	ESC (ETC), ELR
Euro 5	October 2008	2.0	0.02 (0.03)	ESC (ETC), ELR
Euro 6*	2013	0.4 – 0.7	0.01	WHTC, WHSC

ESC: European Steady State Cycle
ETC: European Transient Cycle
WHSC: World Harmonized Steady State Cycle
ELR: European Load Response Test
WHTC: World Harmonized Transient Cycle
Values in parenthesis: ETC
Introduction date for new type approvals; for all type approvals normally one year later
Limit values for CO and HC not shown here
* Euro 6 not defined specifically, decision expected in 2008

Phase	Introduction date	NMHC + NO_x [g/bhp-hr]	NO_x [g/bhp-hr]	Particulate [g/bhp-hr]	Test cycle
US'98	January 1998	-	4.0 (5.36)	0.10 (0.134)	HD-FTP
US'04	January 2004	2.5 (3.35)	-	0.10 (0.134)	HD-FTP, SET
US'07	January 2007	-	1.2 (1.61)	0.01 (0.0134)	HD-FTP, SET
US'10	January 2010	-	0.2 (0.27)	0.01 (0.0134)	HD-FTP, SET

HD-FTP: Heavy Duty Federal Test Procedure
SET: Supplemental Emission Test
Values in parenthesis: g/kWh (conversion factor: 1 g/bhp-hr = 1.34 g/kWh)
Limit values for CO and HC not shown here

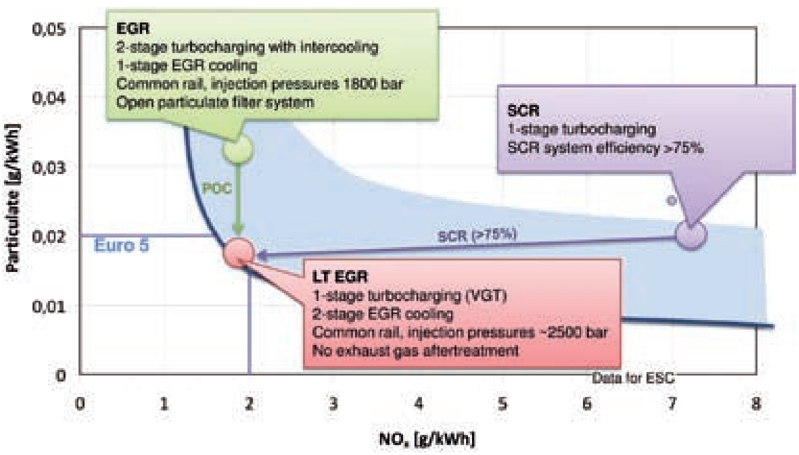


Figure 1: Technologies for Euro 5 – state of the art for the NO_x/PM trade-off

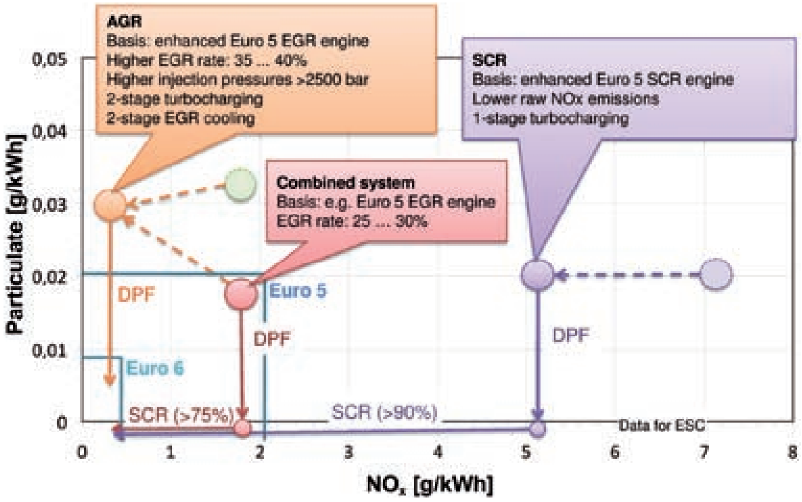


Figure 2: Technologies for Euro 6 – enhancements based on Euro 5

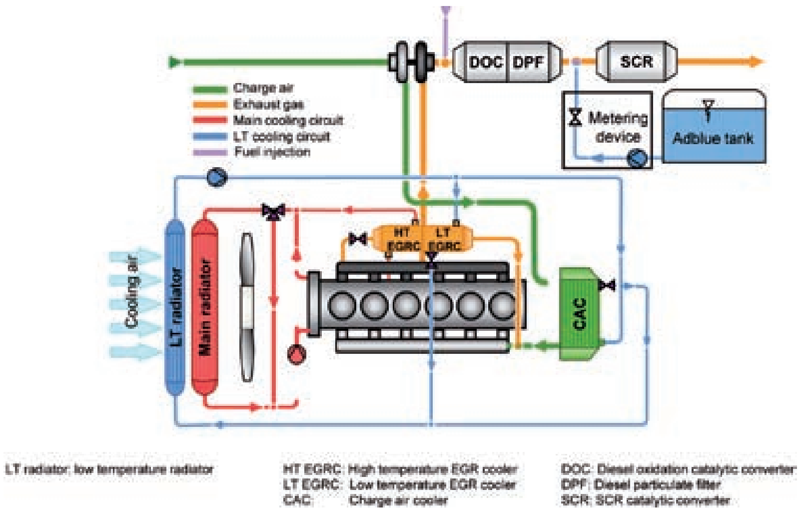


Figure 3: Combined system for Euro 6: EGR and SCR

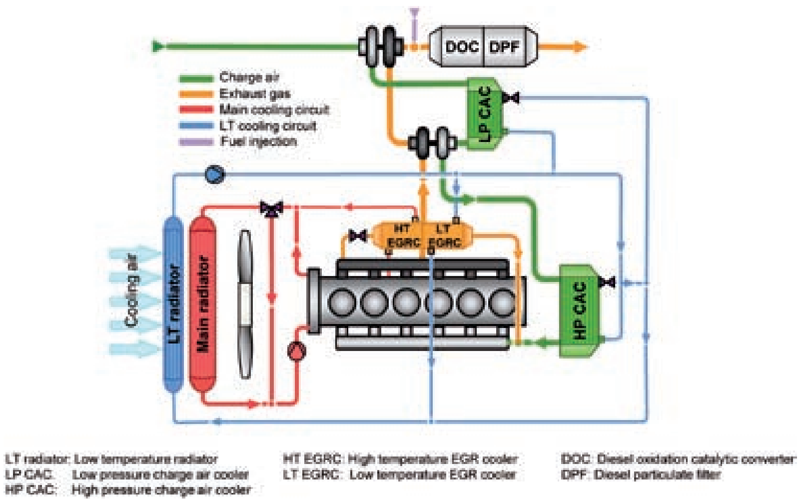


Figure 4: Potential two-stage EGR system for Euro 6

NO_x conversion rate is limited in two ways. In addition, the WHTC includes a cold test which further reduces the rate of conversion in the first part of the cycle. The resulting increase in NO_x emissions probably cannot be offset in the second hot parts of the test.

The transition from Euro 5 to Euro 6 requires an 80 % reduction in NO_x emissions. If this objective is to be achieved with selective catalytic reduction alone, the efficiency of the technology will have to be significantly increased, from around 75 % today to more than 90 %. That is not all: to offset the temperature effect from the new test cycles as described above it will be necessary to further boost the efficiency of the SCR system. Accordingly, it may be difficult to meet Euro 6 and US '10 using SCR alone.

One possible method for achieving the Euro 6 legislation would be to combine SCR and EGR technology, Figure 3. Since cooled EGR means less NO_x is produced in the engine, there is also less NO_x to be converted by catalytic reduction in the exhaust system. The drawback of this combined system, as mentioned previously, is its size and complexity.

4 Exhaust Gas Recirculation with Two Stage Cooling and Two Stage Turbocharging with Intercooling

4.1 Two Stage Exhaust Gas Cooling

Exhaust gas recirculation reduces the oxygen concentration of the cylinder charge, thus reducing the speed and temperature of combustion. Since the rate of NO_x formation is exponentially dependent on the combustion temperature, cooled exhaust gas recirculation is associated with a significant reduction in NO_x emissions. Cooling the exhaust gas also improves cylinder filling and reduces thermal stress on the engine components.

With cooled exhaust gas recirculation, some of the exhaust gas is diverted upstream from the turbocharger turbine and routed to the exhaust gas cooler via an EGR valve. In the case of two stage cooling, Figure 4, the first cooling stage is high temperature cooling (HT EGRC), the cooling medium is the coolant from the main cooling circuit, and in the second cooling stage (low temperature stage,

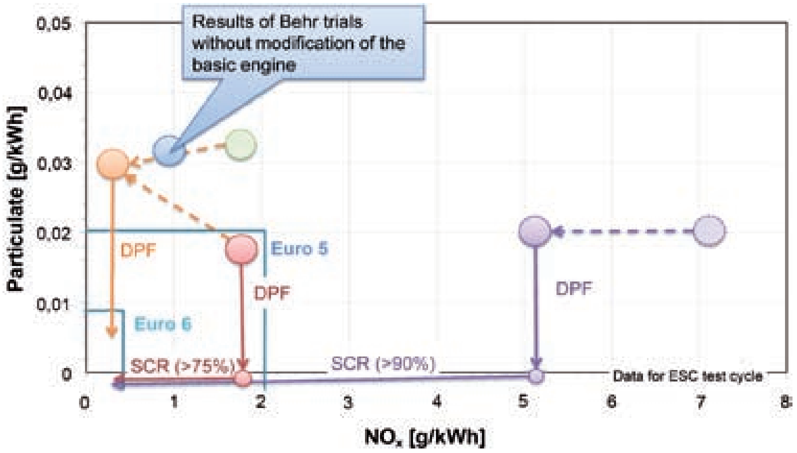


Figure 5: Potential of LT-EGR with respect to Euro 6

LT EGRC), it is the coolant from a low temperature circuit. To prevent the coolant from boiling in the first cooling stage, the exhaust gas and coolant flow in the same direction; the second stage operates in counterflow mode, which improves the cooling performance.

4.1.1 Self Cleaning of the EGR Cooler

A major advantage of two stage exhaust gas cooling – as compared with single stage cooling – is the self cleaning action of the EGR cooler and thus the stabilization of its cooling performance over the life of the cooler. This cleaning action is a consequence of the formation of condensation in the exhaust gas cooler. During the combustion, 1.26 kg of water for every 1 kg of diesel fuel is produced. Some of this steam condenses in the EGR cooler, where the condensation washes the deposits off the tubes of the cooler.

4.1.2 Cooling by Evaporation

Along with this self cleaning action, exhaust gas condensation also reduces the in-cylinder temperatures: firstly by the cooling effect from the evaporation of the charge air exhaust gas mixture and secondly by cooling due to evaporation of the intake air in the cylinder.

Cooling due to evaporation occurs when the condensate in the exhaust gas mixes with the dry charge air and evaporates. The heat required for this to happen comes from the charge air exhaust gas mixture, resulting in a fall in temperature of approximately 10 K. Because of the high dew point of steam, this cooling action occurs at high temperatures, for example 40 to 60 °C.

The exhaust gas condensate evaporates in the intake air but not completely: some water is remains and is conveyed with the intake air into the cylinders, where it evaporates in the compression phase. This second cooling effect limits the increase in the charge temperature during compression, lowering combustion temperatures and, therefore, NO_x emissions.

4.2 Two Stage Turbocharging with Intercooling

Cooling the charge air while keeping maximum cylinder pressures unchanged results in higher performance, lower fuel consumption and less formation of NO_x. In the LP and HP charge air coolers, Figure 4, the charge air, after being heated in each of the two compression stages, is cooled. The cooling of the charge air between the compressors, hence the term "intercooling", improves the efficiency of the second compressor.

4.3 Results

In various tests Behr together with AVL has already reduced NO_x values to about 0.8 g/kWh over the test cycle. However, the optimum has still not been reached. It might be possible to reach the Euro 6 limit, which is likely to be in the region of 0.7 to 0.4 g/kWh, **Figure 5**. It should, however, be noted that low temperature EGR is likely to be successful only in combination with two stage turbocharging and advanced fuel injection systems.

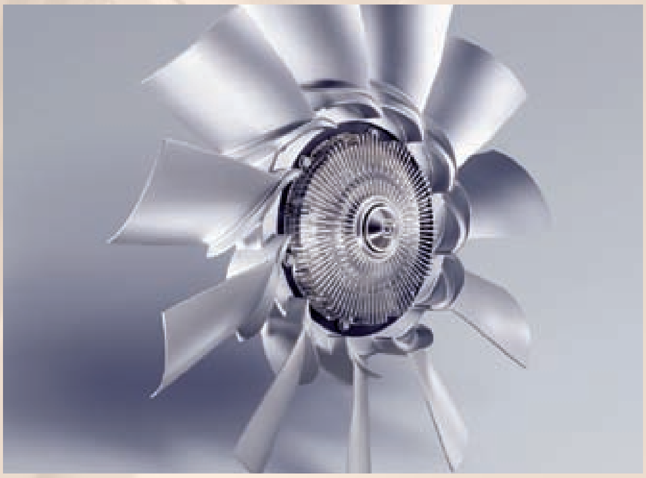
5 Conclusions

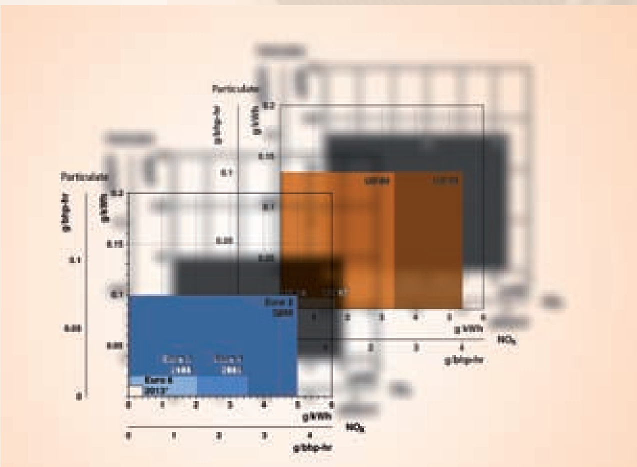
The Euro 6 and US '10 emissions limits are unlikely to be met using SCR technology alone. Cooled exhaust gas recirculation (EGR) will be part of the emissions solution. A combination of SCR and EGR is possible but may have weight, packaging, complexity and cost penalties.

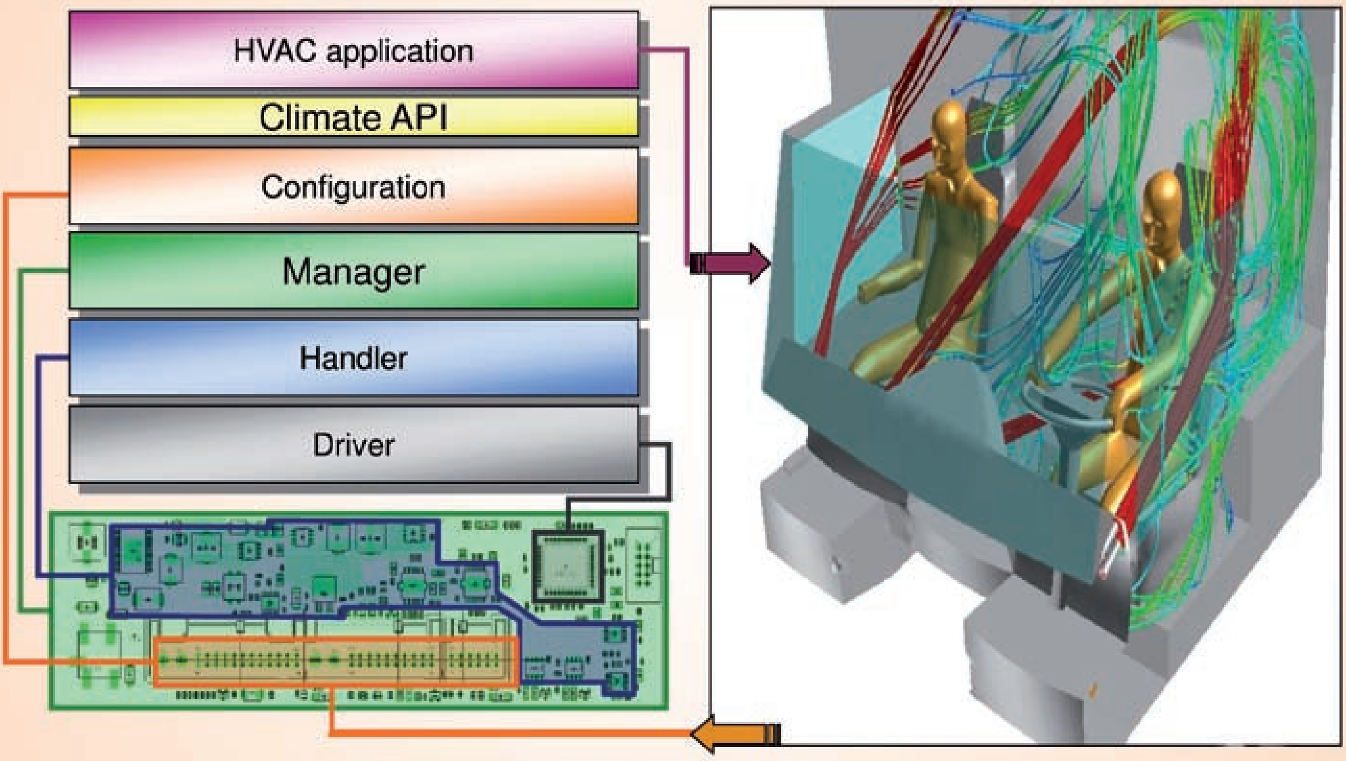
A possible solution is the two stage cooled exhaust gas recirculation process described above, combined with two stage turbocharging. This system possibly has the potential to achieve the potential Euro 6 limits. It should be noted that cooled EGR will also play a key role in enabling off-highway vehicles meet future emissions limits. ■

Special Behr

Thermal Management for Trucks







Ergonomics and Operating Concepts for Trucks

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort.

The Author

Ulrich Scheithauer is chief of product development Truckline/Thermomanagement at Behr-Hella Thermocontrol in Lippstadt (Germany).

1 Behr Hella Thermocontrol

Since the formation of BHTC as a 50/50 joint venture by the Behr and Hella groups in 1999, the company has grown rapidly and today is one of the world's leading manufacturers of control heads for HVAC systems. The product portfolio also includes control units (ECUs) for electric auxiliary heaters, blower controllers, and A/C sensors. The company counts the world's largest car and truck makers among its customers, and serves them not only from its parent plant in Lippstadt, but also from its subsidiary plants in North America, India, China, and, more recently, also in Japan. The BHTC mission is to provide "Comfort in Motion" by creating products that play a key role in ensuring optimum cimate comfort in cars and trucks.

2 Cars and Trucks: Differences in Climate Control

In recent years, there has been a sharp increase in comfort requirements for truck cabs. The driver's space is now recognized as a proper workplace. Ever more importance is accorded to the climate in the vehicle cab. Features that have long been standard in passenger cars have for some years now also been making their way into commercial vehicles. Today, no manufacturer can ignore its customers' demands for greater climate comfort. However, optimum climate comfort benefits not only the driver, but also all other road users as well: high interior air quality and a pleasant cab climate improve drivers' performance and help them to concentrate on the traffic.

Comfort is not only enjoying a pleasant climate in the driver's cab, but also the rapid response of the climate control system to changing climatic conditions. The system can thus ensure constantly mist-free windows and draft-free temperature control of the driver's workplace. The dash vents and the ventilation blowers are controlled in such a way that virtually no condensation forms on the windshield and side windows, and unwanted drafts are avoided.

Sensors measure the temperature at each of several points in the A/C system, and compensate for the influence of incoming solar radiation that falls directly onto the non-ventilated cabin temperature sensor. The climate control system can thus react quickly to changes.

Nevertheless, there are differences in the air conditioning of passenger cars and commercial vehicles that make the direct adoption of HVAC modules and control concepts from passenger cars impossible, **Figure 1**:

- A larger cab volume, and higher cabs.
- Commercial vehicles usually have a large, but vertical windshield. Compared with passenger cars, this results in less heat from solar radiation entering the cab in the middle of the day.
- Generally, the windows do not feature heat-absorbing glass comparable with that of passenger cars, and this results in a greater influx of heat when the sun is low.
- Cold outside temperatures, if they are not adequately compensated for by air conditioning, can result in an unpleasant flow of cold air at the windshield, leading to cold arms and thighs.
- Increased use as a result of ever denser traffic and frequent changes of drivers call for more user-friendly controls, that means it is important for the operator to quickly and intuitvely understand how the air conditioning system works.
- Owing to the greater movement range of the driver's seat, the operating controls must be larger and clearer in terms of their functional classification.
- The effect of the center air vent in the instrument panel is generally not so intense, owing to the greater distance to the driver.
- All system components must be designed for a longer service life.
- Today, some passenger cars have multi-zone climate control systems that must react more quickly to the changing amounts of incoming solar radiation due to the large sloping windows.
- Long-range trucks have a sleeper cab, which, in stationary operation, increasingly requires not only controllable heating, but also air conditioning; see the presentation on no-idle air conditioning.
- Passenger car platforms with high unit numbers of individual model series require specific climate control hardware and software components that are based on a standard module set. Control heads for truck air conditioning systems are also designed for platforms, but because the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software, **Figure 2**.

3 The New Climate Control System for the MAN TGX

For the design of the A/C control heads and ECUs for the air conditioning systems for the new MAN TGX, a modular concept was adopted from the outset. This concept makes a clear distinction between design and functionality.

The control head for the air conditioning system was thus integrated into the modern cockpit with significant space savings, and adapted to an individual design that meets demanding ergonomic and functional requirements. In all variants, mechanical Bowden cables from the control head to the HVAC system are dispensed with, and only six electric cables are used to connect the control head and ECU.

4 The HVAC Control Head

As the functionality of air conditioning systems increases, their operability often decreases. Especially in the case of commercial vehicles, owing to the long travel times with dense traffic, frequent changes of drivers, and the large movement range of the driver's seat, clearly identifiable and understandable controls are important.

We already provided an in-depth report on the link between operating ergo-

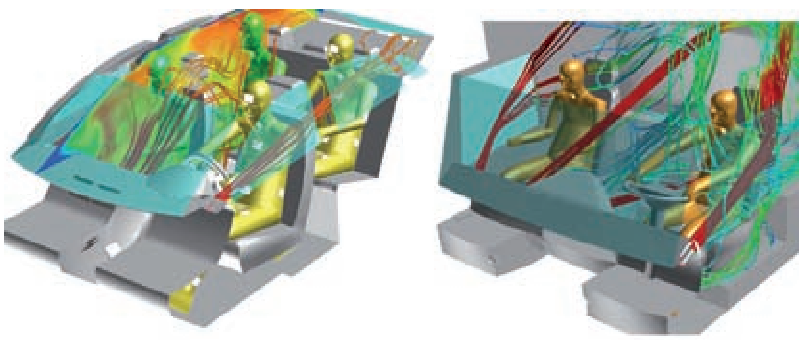


Figure 1: Cabin volume, layout and size of the windshield make up the big difference in the climate control between passenger cars and commercial vehicles

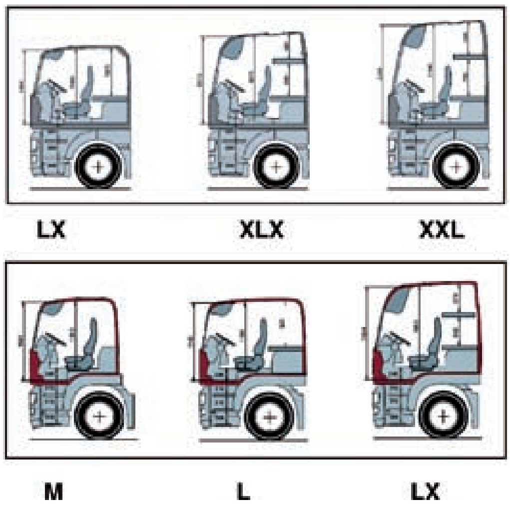


Figure 2: In commercial vehicles, the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software

nomics and traffic safety and a operability studiy carried out with the Technical University of Munich in 2007. Inadequate ergonomics lead to significant risks in traffic situations. The results show that easily recognizable symbols are based on:

- symbols/graphics
- depictions of people
- depictions of seats
- a vehicle contour to back up the symbols
- a combination of text and symbols.

Whereby symbols that are not easily recognized often contain text with no symbols, abstract symbols, or symbols that deviate from the international ISA standard.

The control heads for the MAN TGX therefore reflect the state of the art in relation to operating ergonomics, Figure 3.

In the fully automatic air conditioning unit, the driver selects both the desired air distribution and the blower speed by means of two control dials. The driver sets the temperature by means of two buttons, and the selected temperature is shown in a display. In the simpler heating variant, the temperature is set using the left-hand control dial, while the blower speed is changed by means of two buttons. In this A/C control head, particular importance was placed on easily understandable operation and ease of identification of the symbols for the switches and the display by both day and night. This is particularly important for trucks since they are driven for much longer periods, and also at night. It was therefore important to have highly contrasting images and clarity of symbols. This requirement was satisfied in all of the device variants by means of fail-safe LED lights, high-quality plastics technology for the operating buttons, and lasered symbols. In this way, with backlit symbols, no light can escape from the button control panel. Drivers receive an unambiguous acknowledgement from the system via the display in all control head variants, and can thus give their full attention to the traffic.

In the automatic mode of the fully automated system, the blower output temperature adjusts itself independently according to the vehicle's boundary conditions.

All the necessary settings for the air conditioning in the driver's cab and the sleeper cab in the new MAN TGX und TGS vehicles can be operated using a maximum of ten buttons and two control dials. One control head is therefore used to control both the driving and stationary operation. A second control head in the rear is therefore not necessary.

In order to ensure that the device has a long service life and is robust, and requires no maintenance, a non-ventilated interior temperature sensor (ITOS), Figure 4, was also used instead of the customary ventilated interior temperature sensor. The cab temperature is measured using the robust and maintenance-free sensor, and this is compensated for by means of a customized control system taking into account the incoming solar radiation, and also the heating of the device itself.

5 The Air Conditioning ECU

In the MAN TGX, a standardized air conditioning ECU was used for the first time. Behr and BHTC are thus responding to customers' demands for ever-smaller packaging dimensions of the control head and an individual design of the instrument panel with maximum control functionality.

For the climate control, a functional separation of the ECU and the A/C control head was selected, Figure 5. The heart of the ECU is a printed circuit board of modular construction and of standard dimensions. Thanks to the standard printed circuit board, the dimensions of

Figure 3: The control heads for the MAN TGX / TGL reflect the state of the art in relation to operating ergonomics

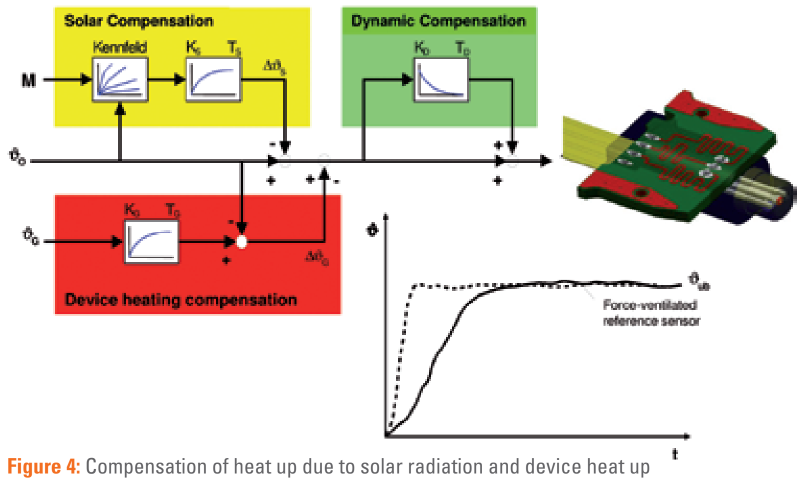


Figure 4: Compensation of heat up due to solar radiation and device heat up

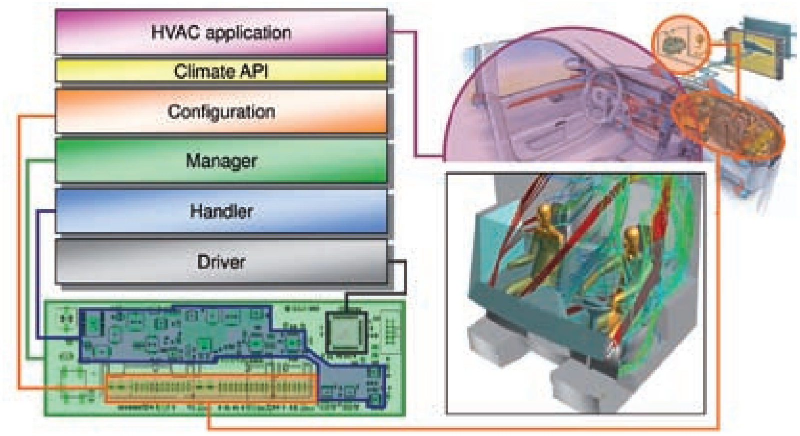


Figure 5: Architecture of the standardized air conditioning ECU – separation of function and design

the ECU and the connector plug are identical for all variants.

The ECU is installed in the vehicle in such a way that the HVAC module and ECU form a functional unit with short electrical connections. A mechanical coupling between the control head and the HVAC module is no longer required. In addition to the preferred mounting position on the HVAC module, other mounting locations in the vehicle are, in principle, also possible.

The open architecture and the less complex design of the control head give the customer more freedom in the design of the instrument panel in the vehicle than before, and better use is made of the existing space envelope. Other variants adapted to the customer's requirements can be obtained only by means of a different assembly and different programming of the processor. This reduces the development outlay required for variants, and cuts costs. The ECU is also flexible in terms of the interface to the customer's preferred data bus format.

6 Summary

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort. Operation of the air conditioning unit must respect ergonomic considerations, so that drivers take advantage of all of the capabilities of the A/C system on the one hand, and are not distracted from the traffic by its operation on the other.

With the unit's design and operating concept, BHTC has satisfied the increasing demands for an A/C control head that is modern, efficient, and at the same time user-friendly.

Whatever the initial climatic conditions at the start of the journey, or however they change during the trip, the climate control system always ensures consistently comfortable and draft-free air conditioning, and thus avoids any additional stress for the driver.

A climate control system that is functionally and ergonomically designed using state-of-the-art processes thus plays a key part in reducing the stress on drivers, and, thanks to the comfortable cab conditions, helps them stay relaxed in every traffic situation. ■

Non-idle Air Conditioning for Enhanced Road Safety and Reliability

Transportation of freight by truck is very important for the functioning of the economy and society. As the driving condition of the driver plays a key role in this, it is essential to provide adequate thermal and acoustic comfort during rest periods. A non-idle A/C system that provides air conditioning both during journeys as well as during rest periods and when the windows are closed, improves driver recuperation. The driver is thus better able to concentrate and feels fitter and more refreshed.

The Author

Dr. Lubens Simon is chief of commercial vehicle climate systems development at the Behr GmbH & Co. KG in Stuttgart-Feuerbach (Germany).

1 Introduction

Transportation of freight by truck plays a key role in the functioning of the economy and society in all Western countries. It is even more important that this transportation takes place in a safe, reliable, and eco-friendly manner, and that it is cost-efficient. Drivers play a key role in achieving this: their health, ability to perform and to concentrate, in short: their driving condition. In order to maintain this condition at a high level for the entire duration of the journey, drivers require a workplace that is ergonomically designed and has a pleasant cab climate.

This involves a high level of thermal and accoustic comfort, which is important not only during the journey itself, but also when any stops are made, whether they are voluntary or involuntary. The thermal comfort is particularly important in driver rest periods, because otherwise the degree of recuperation is reduced. This applies especially to the sleeping phase, since drivers who are not well-rested pose a danger to themselves and to other road users. The infamous "miscrosleep," one of the greatest causes of accidents, is primarily due to inadequate or unrestorative sleep. Non-idle air conditioning, that cools the cabin also during the rest periods with windows closed, enhances the thermal comfort of the driver and thus his ability to concentrate.

2 Driver Survey on the Use of Non-idle A/C Systems

In 2006, Behr surveyed 500 truck drivers from different countries with different vehicles at a total of six rest areas along Germany's main highways. The aim of the survey was to find out how the drivers use the cab as a living space, and what the requirements of this living space are (with a focus on air conditioning), and also what the future requirements of the market are, and which product strategy can be developed from this information.

After this general questioning, 16 drivers were selected for a longer interview. These people formed a representative market cross-section of long-distance drivers who had a non-idle A/C system.

It was found that the great majority of the drivers believe that a non-idle air conditioning unit is important. Around 90 % of the drivers who did not have this sort of system in their vehicle would choose to have one. Since only one fifth of all long-distance trucks are equipped with non-idle vehicle air conditioning, there is a very high market potential. By contrast: parking heating systems are found in all heavy-duty trucks. A summary of the driver's views: Non-idle air conditioning systems ...

- ... are used in a similar way as parking heaters, and are valued just as highly by drivers
- ... are nevertheless available commercially only at a market level of 20 %
- ... are perceived as improving drivers' personal safety
- ... avoid engine idling, and thus prevent fuel consumption and engine wear
- ... should provide air conditioning at night for up to ten hours, and for up to two hours during the day with incoming solar radiation
- ... should provide automatically controlled air conditioning for the entire cab
- ... should not require any servicing or any initial activation.

According to this information, non-idle air conditioning systems have a high market potential. From these and further results of the survey, the following specifications have been provided:

Non-idle air conditioning systems should ...

- ... cool the cab during overnight stops for up to ten hours and for up to two hours during the day (even with strong incoming solar radiation)
- ... provide draft-free cooling of the entire cab (not only the space above the bed)
- ... have automatic temperature control
- ... be reliable and easy to operate
- ... not require any maintenance; the charging of the energy storage devices (cooling battery or battery pack) should occur automatically
- ... be interfaceable with an automatic fresh air supply.

The requested hours of operation and performance can be fulfilled by electrical systems. Also, roof units will fulfill the expectations on non-idle a/c units. The non-idle air conditioning systems currently available on the market are still highly inadequate compared with what drivers want in terms of both their technology and their performance. In order to satisfy all of the requirements of the users, Behr has set itself the following additional design objectives for non-idle air conditioning systems:

- a low current draw in order to allow battery pack operation
- installation in existing roof openings for aftermarket applications
- satisfy truckmakers' installation requirements, specifically in terms of quality, durability and reliability and integration into the operating system architecture.

On the basis of these design objectives, an electric non-idle air conditioning unit

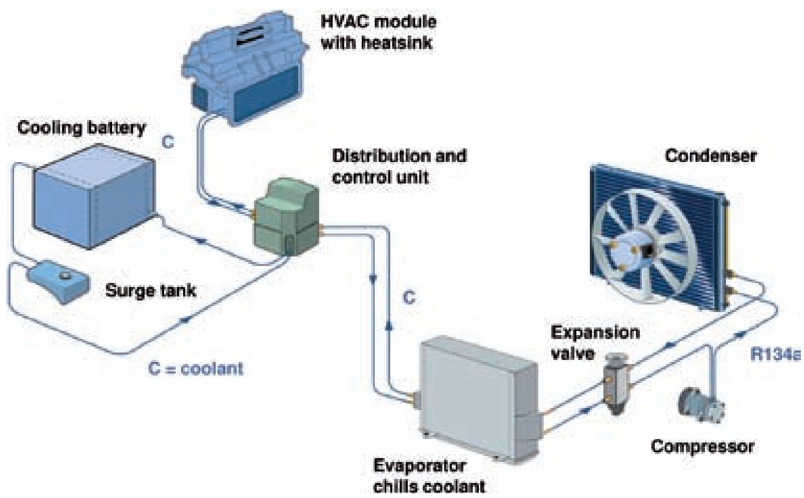


Figure 1: System diagram of the non-idle air conditioning with cooling battery from MAN

in the form of a roof unit was designed and constructed as a demonstration model, in addition to the non-idle air conditioning system with a cooling battery that is already in series production. Design of a rear wall unit is currently under way.

3 Technical Features of the Cooling Battery System

The non-idle air conditioning system with a cooling battery is fully integrated in the vehicle, and replaces the conventional engine-driven air conditioning system. The system has a secondary circuit **Figure 1**. In the charging phase, a conventionally operated refrigerant circuit intensely cools a liquid refrigerant in a special evaporator. This coolant, controlled by the distribution unit, cools both the heat sink in the HVAC module as well as the contents of the cooling battery, which therefore freezes. The heat sink replaces the conventional evaporator in the HVAC module; it cools the cab air during the journey, and during breaks in the journey. In the non-idle A/C system, the refrigerant circuit is in the resting state. By means of the circulating refrigerant, the heat from the vehicle cab is slowly transferred to the cooling battery, where the frozen content of the cooling battery is liquefied. The system with the cooling battery is fitted as standard in the heavy commercial MAN vehicles TGA (since 2003) and the more recent TGX from MAN (since 2007).

4 Technical Features of the Roof Air Conditioning Unit

This plug-in 24-V unit can either be factory fitted or retroffited on the aftermarket. The unit is made up of an electrically operated, conventional refrigerant circuit that essentially consists of a compressor, condenser with fan, receiver, blower, and evaporator with expansion device, **Figure 2**. These components are housed in a single module that projects into the roof opening of the vehicle. Inside the cab, a screen allows drivers to see only the air inlet and the air outlet openings, and the control head. **Figure 3** shows a cross-section through the roof unit installed in the ceiling of the cab, and how it works.

The unit is operated with recirculated air. Control of the fresh air supply is integrated in the control system of the engine-driven air conditioning unit. For the power supply, in addition to the starter batteries, an additional battery pack, for example consisting of lead-gel batteries, must be provided in the vehicle. Some of today's systems are, in fact, powered by conventional starter batteries, but these are not really suitable for operating non-idle air conditioning systems because they are designed to deliver a high current over a short period of time. The non-idle air conditioning system must, however, be supplied with power over several hours. In a nine-hour operation, the battery is almost completely drained, and thus needs to be recharged. If a starter battery was frequently charged and drained, its capacity would quickly be reduced even after 15 such cycles to under 40 %. Starter batteries are therefore unsuitable for this application.

Lead-gel batteries, by contrast, are cycle-proof, that means they can be repeatedly recharged to a high capacity.

The roof air conditioning unit provides sufficient power to air-condition the cab, even with incoming solar radiation during the day. The two-hours-per-day period of operation determined from the driver survey is not, however, the critical value for the battery pack, but instead night operation of up to ten hours. In the case of an average power consumption of the unit of only 400 W, this would require, for example, a battery pack with four standard size traction batteries. The low power consumption of 400 W is the result of the system's exceptionally high efficiency.

Figure 4 uses measured values from the Behr climatic wind tunnel to show the course of air conditioning at night

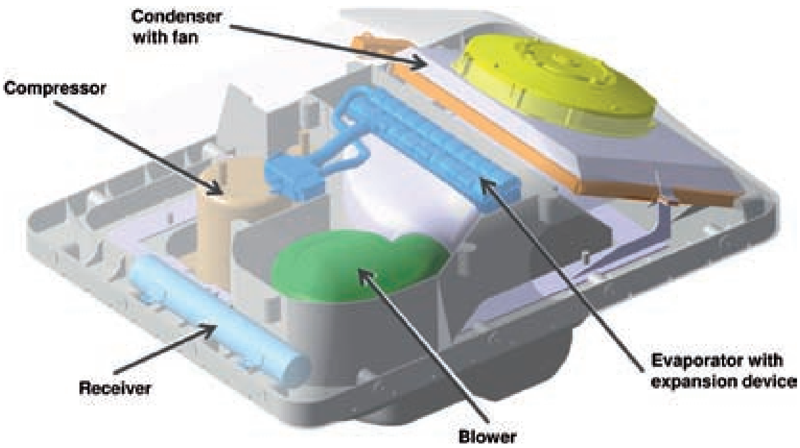


Figure 2: Schematic depiction of the electrial roof air conditioning unit

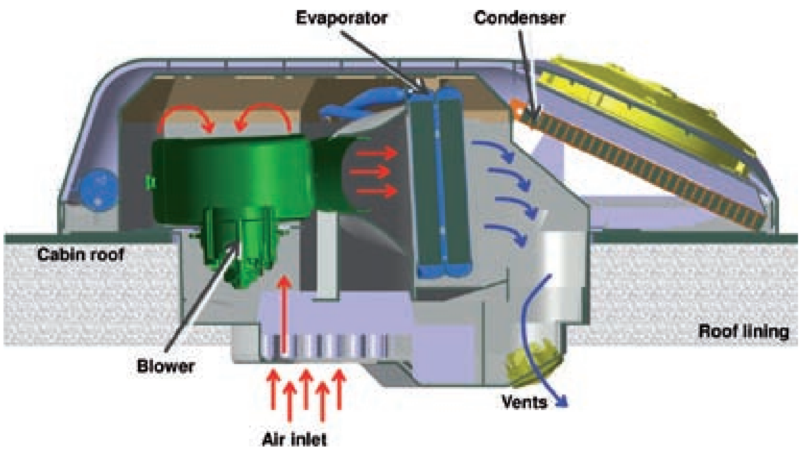


Figure 3: Side view of the electrial roof air conditioning unit

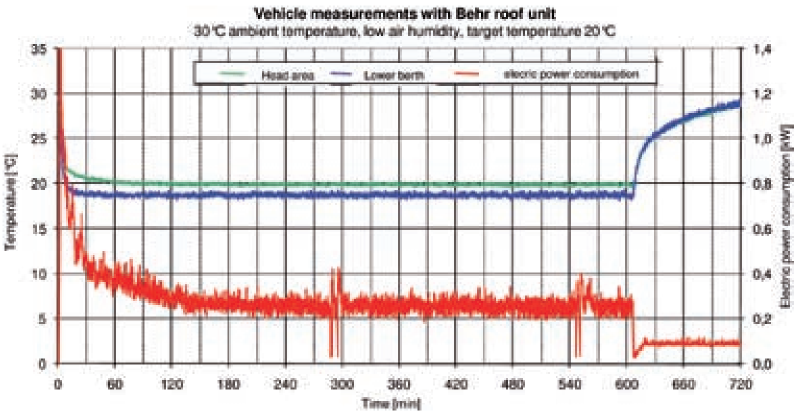


Figure 4: Cool down and power consumption of the electrial roof air conditioning unit at night

with an outside temperature of 30 °C. The target temperature of 20 °C is very quickly achieved and maintained, thanks to the temperature control over the ten hours. The power consumption is almost always less than 400 W.

5 Advantages of the Electrical System

The electrical system has two advantages over the system with the cooling battery: for one thing, drivers can access the cooling capacity at almost any time, because the batteries can store the power supplied by the generator for a long time. They therefore do not need to plan the charging or even to initiate it, since this happens automatically. During the journey, the battery pack is then constantly maintained in the fully charged state. In the system with the cooling battery, the charging of which is initiated manually, it is not possible to exclude the possibility that the driver may one day forget to initiate the charging, or may initiate it too late. If cooling is then required, there may be no or insufficient cooling capacity available. This point was also mentioned in the driver survey, which then also led to the call for an automatic charging of the cooling battery or battery pack.

The second advantage of the electrical system is that, with the battery pack for the non-idle air conditioning unit, additional electrical devices can also be operated, for example a television, computer, microwave oven, or coffee machine. Because the starter battery need not be used to do this, it therefore cannot be drained accidentally.

6 Behr's Development Capacity

As an original equipment manufacturer and systems supplier of passenger car and truck air conditioning units, Behr designs not only the HVAC modules, but also the control heads and associate software, working with joint venture companies such as Behr-Hella Thermocontrol (BHTC). This calls for expertise in the communication processes in the vehicle and for close collaboration with the vehicle manufacturers, for example for the construction of an interface between the engine-driven and non-idle air conditioning systems. Such an interface is required, for example, when the fresh air supply to the cab is to be taken over by the engine-powered A/C system instead of the non-idle air conditioning unit. This is particularly desirable when the truck's engine-driven A/C system is equipped with active carbon filters. In this case, the cab is supplied with filtered, gas-free air that increases drivers' safety when they are asleep. Generally, the fresh air is supplied at intervals, activated, for example, by a timer. The timed control saves battery power, but still guarantees an adequate supply of fresh air.

7 Summary

Non-idle air conditioning systems have considerable market potential, comparable with that of parking heaters, with which almost 100 % of long distance trucks are equipped. Behr's electrical units satisfy all relevant performance requirements, and have proven to provide a higher cooling capacity and higher efficiency than all comparable systems. A further advantage of the Behr units is their reliability, because the system components were designed specifically for use in trucks, and are sourced from series production of vehicle air conditioning units. ■

Measures for Satisfying Future Exhaust Emissions Standards in Special-purpose Vehicles

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US '10 envisages another drastic reduction in NO_x emissions for commercial vehicles.

1 Behr Industry

When Behr Industry was founded in 1990, the objective was to cater to special markets in the engine cooling and air conditioning sectors. The justification for this was that technical and legal requirements were made with respect to the components and systems of off-highway vehicles that were completely different from those for the passenger car and commercial vehicle markets – requirements that cannot be satisfied by simple modification of an existing component or of an existing system.

The split of Behr Industry and Behr GmbH & Co. KG essentially reflects our customer structure, since Behr's customers often operate in different market segments, and under different names. Today, Behr Industry is active in the markets for buses, heavy-duty engines, railway vehicles, aircraft, construction and agricultural vehicles, electronics, military products, and gensets (that means diesel-engine driven generators for generating electricity). The most important requirements are:

- The smaller production volumes or even single unit productions, also mean, that different development procedures, manufacturing technologies, and logistic concepts are necessary.
- The Euromot, EEV, and Tier X legislation governing emissions and CO_2

emissions is very similar to the Euro 5/6 and US 'XX standards from the car and truck vehicle sectors – only time-displaced by about three years.
- Other constraints on cooling requirements, installed position, and the available installation space.
- In the special-purpose vehicles, the components and systems are exposed to different stresses: fouling through mud, dust, and fibers results in different focuses for the development of heat exchangers. In some shipbuilding applications, cooling takes place using the seawater itself. The corrosive action of the saltwater is countered with special stainless steel.

2 Small-scale Series Production

For example for buses, small-scale series production specifically means annual volumes of approximately 500 to 3000 units. In the case of railway vehicles, the figure can be as low as just five to 100 units per year. Behr Industry must therefore use other processes for manufacturing radiators and coolers and for assembling complete cooling systems. Semi- or fully automatic production equipment can be used only rarely, and the costs of die-casting or functional plastic components often cannot be redeemed, owing to the high capital costs involved. Flexible systems are called for that require little or no capital expenditure; however, these demand higher manual production outlay and highly skilled manufacturing staff. Behr Industry also endeavors to carry over products or components from high-volume series production and integrate them (for example buses and tractors) in order to take advantage of the cost benefits of large-scale series production. This significantly reduces R&D expenditure, validation requirements, and the risk of failures in the field.

Behr Industry also employs the general Behr production standards and development tools and tests and develops its products in the test facility of the parent company, and uses the same simulation tools (FE analyses, CFD calculations, BISS). This makes the development of new products specifically catering to special market requirements efficient and competitive.

3 Exhaust Emissions Standards

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US 10 envisages another drastic reduction in NO_x emissions for commercial vehicles. The corresponding standard for the off-highway sector is Euromot stage IIIB / Tier IV A, and will come into effect approximately three years after Euro 5 / US 10. The limits for NO_x and particulate emissions are not much different from those of commercial vehicles: Euromot stage IIIB envisages a reduction of nitrogen oxide emissions to 2 g/kWh, and of particulate emissions to 0.025 g/kWh (Euro 5 specifies 2.0 NO_x and 0.2 PM).

The exhaust emissions standards for off-highway vehicles in the USA are similar. The standards that are similar to the US07 and US10 standards are the Tier 4a and Tier 4b standards, which will come into effect at the same time as Euromot stage IIIB, that means three years later.

In the bus market, we find a special situation; here, the EEV (Enhanced Environmental Friendly Vehicle) preliminary standard was introduced. EEV is not a mandatory limit, but rather a voluntary standard that is virtually no different from Euro 5 in terms of the limits on NO_x and particulate emissions. EEV engines essentially already satisfy the Euro 5 standard that will be in force from 2009. The environmental awareness of the bus operators, in particular in large cities, leads to their voluntarily complying with special limits as per EEV.

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In order to comply with the exhaust emissions regulations and to save fuel in off-highway applications, as in the case of commercial vehicles, systems such as cooled exhaust gas recirculation or two-stage turbocharging are used, **Figure 1**. Here, too, this similarly leads to increasingly complex cooling systems every time the exhaust emissions laws are tightened further. Higher charge air temperatures and pressures and quantities of heat in the coolant call for new solutions for heat exchanger design. The integration of cooled exhaust gas cooling and indirectly cooled charge air requires considerable systems expertise in order to be able to guarantee the necessary cooling within the special constraints of the off-highway market.

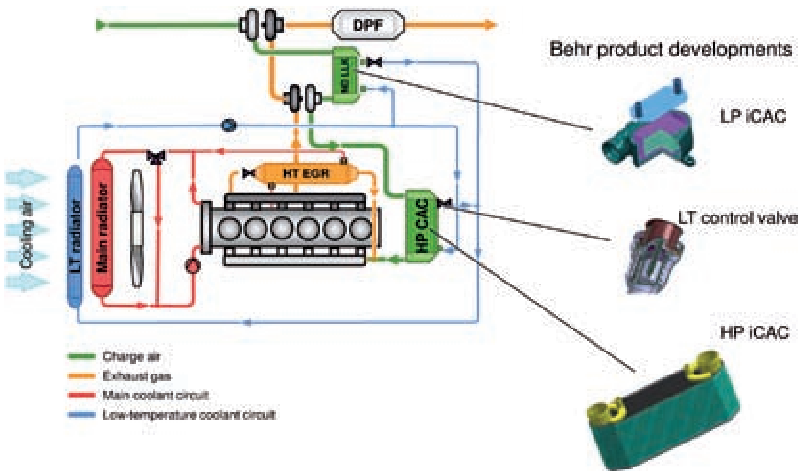

Figure 1: Schematic representation of a two stage turbocharging with indirekt charge air cooling

4 Fouling

A distinctive feature of special-purpose vehicles is their use in very different areas of application: mines, fields, rails, water, construction sites, forests, or garbage dumps. Fouling on the external surface through which cooling air passes thus takes very different forms. Sand, dust, oils, pollen, leaves, plant debris, grass, litter, and many other soiling agents in every possible combination accumulate on the air side inside the radiator and between the fins, Figure 2. This leads to a higher air-side pressure loss and restricts the flow of cooling air. The radiator can no longer provide the desired cooling power to the engine, and engine performance decreases accordingly.

Here, conventional radiators with louvered corrugated fins cannot be used. Behr Industry has developed special cooling air fins specifically for these applications. Unlike conventional fins, these do not have any louvered structure on their surface; instead, they are flat or corrugated. In car or truck radiators, these louvers serve to improve heat transfer between the cooling air and the cooling water, because the air does not pass through the fins in a laminar flow, but instead turbulence is produced on the louvers, Figure 3. However, a lot of dirt particles collect on these louvers that cannot be removed by using compressed air, for example. If there are no louvers, dirt particles can be blown away against the direction of flow.

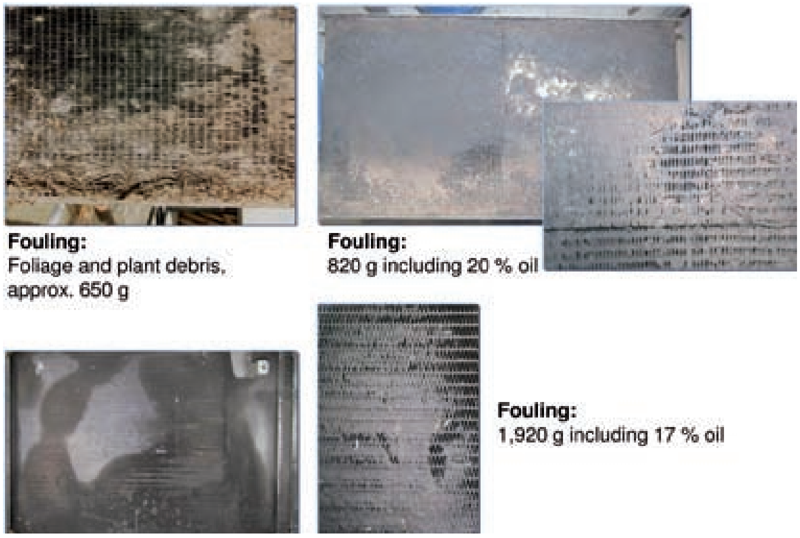

Figure 2: Representative examples of different foulings as found in off-highway applications

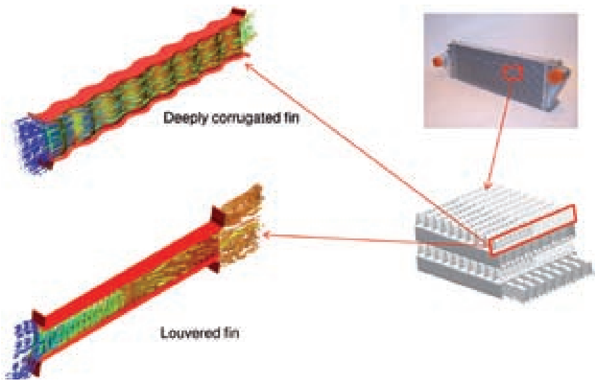

Figure 3: Comparison of a deeply corrugated fin and a louvered fin

In order to understand the mechanisms of fouling and to draw the appropriate technical conclusions, Behr Industry has been working closely with a number of institutes for several years. Figure 4 and Figure 5 show the results of tests on different cooling air fins that were realized in collaboration with the ILK Dresden (Institute of Air Handling and Refrigeration Technology in Dresden). These tests investigated to what extent the pressure drop on the cooling air side is dependent on the dust concentration and the fin used. It was found that the flat fin has the smallest pressure drop. Figure 5 shows the results of similar tests, but under more realistic conditions using fibers as the fouling agent. A flat fin, a staggered fin and a louvered fin were exposed to fibers during usage and the cooling air side pressure drop was measured over time. After a predetermined cycle had been completed, the fins were cleaned with compressed air. It is observed that the pressure drop in the louvered fin is worse after every cleaning cycle compared with the flat fin and the fin with deep corrugations. This is because fibers penetrate deep inside the fins, and, in the louvered fin in particular, can then no longer be removed. Therefore, over time, the radiator with the louvered fins becomes clogged up, and can no longer be cleaned.

Of course, the efficiency of the radiator decreases with the soiling of the louvers. Together with our customers, we must therefore arrive at a compromise between the prevention of fouling and the performance density of the radiator.

Furthermore, the arrangement of the individual coolers (radiator, charge air cooler, etc.) can play a role in minimizing the susceptibility of the cooling module to fouling. In conventional radiators, the individual radiators are arranged one behind the other ("face to face"). The problem here is that dirt particles may pass through the first radiator and become caught in the second one. For cleaning, the cooling module would have to be dismantled. To avoid this, the radiators can be arranged next to one another ("side by side"), so that all of the faces can be cleaned from the outside. Alternatively, the frame of the cooling module can also be designed to swing open, in order to facilitate cleansing of the second radiator, Figure 6.

5 Systems Expertise

All of these requirements must be implemented for a small market that individually caters to specific customers. Behr Industry provides not just the coolers and

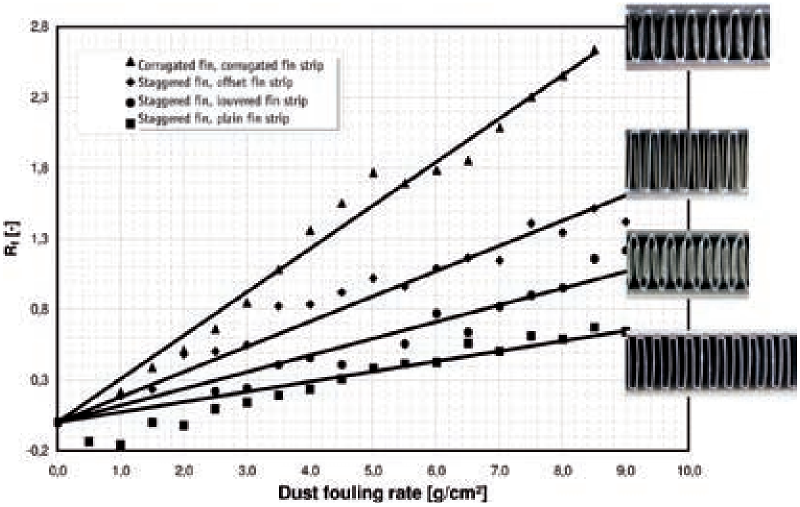

Figure 4: Fouling: Impact of dust on the pressure loss in coolers. Investigations performed by ILK Dresden on behalf of Behr Industry

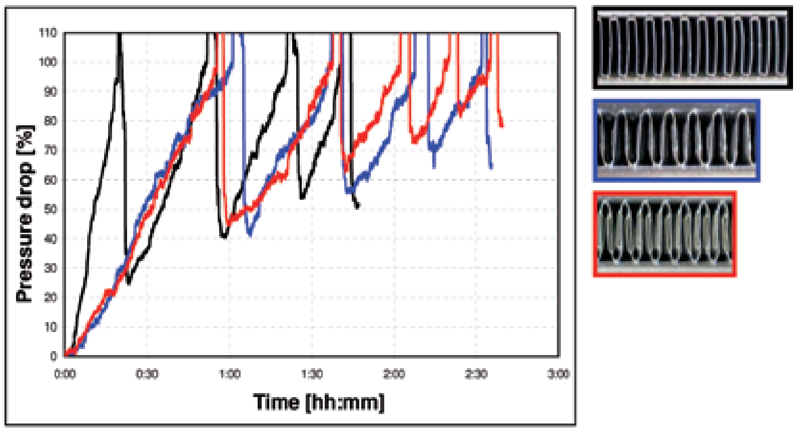

Figure 5: Fouling: Impact of fibers on the pressure loss in coolers and the regeneration of coolers with different fins. Investigations performed by ILK Dresden on behalf of Behr Industry

Figure 6: Solutions designed to prevent fouling – cooling module for city bus featuring swing-out device (top); tractor cooling module with coolers arranged in parallel on the cooling air side (bottom)

radiators themselves, but also complete ready-to-install cooling systems including the radiator/coolers, fan, fan drive, frame, and, if required, also the surge tank, water and oil pumps, and level controller, working in close collaboration with and for its customers.

When solving these technological problems, Behr Industry calls on Behr‘s development methods, results and products, as they are described in the article “Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles”. Behr Industry uses this technology and adapts it to suit the respective engines and the needs of the different special markets. Indirect charge air cooling is standard in commercial vehicle engines. The corresponding indirect charge air coolers are designed in a stacked plate construction. Behr Industry adapts the coolers for a potentially higher engine power. This can be achieved with a simple scaling, that means an increase in the quantity of stacked plates, for example, or, alternatively, by means of bundling existing EGR coolers when there are very high quantities of exhaust gas in the cooled exhaust gas recirculation, for example.

Because the installation position of the engines in special-purpose vehicles is often different from that of conventional commercial vehicles, adapting the components for the new installation position represents another challenge.

If the installation position changes, very often the air ducting on the cooling module or the position of the surge tank relative to the radiator changes as well. In conventional applications, the cooling air is routed from the front through the radiator into the engine compartment. In railway vehicle applications, for example, this is often not possible, owing to the installation position. In roof units, the air is conveyed laterally through the radiator and leaves the module at the top. In other locomotive applications, the radiators are located at the bottom of the module and the cooling air is routed through the assembly from the top to the bottom. If the surge tank for the cooling medium cannot be mounted above the radiator, technical solutions such as an anti-cavitation tank or two-chamber system must be found in order to ensure that the cooling circuit remains free of air. ■

In recent years Behr has made such progress in developing cooled exhaust gas recirculation and iCAC systems that commercial vehicle manufacturers now have at their disposal reliable, production-ready solutions for reducing NO_x emissions. When used in combination, these new cooling systems can meet Euro 5 emissions requirements without the need for a special exhaust treatment process such as selective catalytic reduction (SCR).

Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles

The Author

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1 Introduction

And in contrast to SCR, these innovations do not require any additional operating agent. When they are used in conjunction with the latest engine and injection technology there is no increase in fuel consumption, and they also allow weight reductions at comparable costs. Further benefits are the flexibility of application of these new solutions, and their high potential for further development to meet Euro 6 requirements.

2 Emissions Standards and Reduction Technologies

2.1 Emissions Standards

Since 1992 (Euro 1), the limits for heavy trucks have been brought down in five stages, including some very drastic reductions. Since 2000 (Euro 3) emission limits for NO_x have been reduced from 5 to 2 g/kWh, and particulate emissions from 0.10 to 0.02 g/kWh. In percentage terms this corresponds to a 60 % reduction for NO_x and 80 % for particulates.

2.2 Exhaust Air Cooling and Charging

The exhaust gas recirculation process is essentially based on the fact that the exhaust gas has a higher heat capacity and a lower oxygen content than air. This causes the combustion temperatures in the cylinder to fall. The cooling of the exhaust gas and the charge air makes the temperatures drop even further. Because NO_x formation is an exponential function of these temperatures, a combination of cooled exhaust gas recirculation and turbocharging with CAC was able to meet the Euro 4 limits. Compliance with the stricter requirements of Euro 5 requires either an increase in EGR rates or a reduction in exhaust gas and charge air temperatures. The single stage EGR with two stage turbocharging plus intercooling, and two stage cooled EGR with single stage turbocharging are available for this purpose.

3 Engine Cooling Systems for Euro 5

Over the last few years Behr has been investigating how the increasingly stringent limits can be met by improving engine cooling. In particular, efficient charge air and exhaust gas cooling have a positive effect both on NO_x formation in the combustion chamber and fuel consumption. The newly developed production-ready engine cooling systems for Euro 5 and their components are described below, including comparisons with the SCR system.

3.1 Engine Cooling System with Single Stage Exhaust Gas Cooling and Two Stage Turbocharging

Figure 1 is a functional schematic of such a cooling system. It comprises an exhaust gas cooler which is cooled by the engine coolant, and a low temperature (LT) cooling circuit which contains two charge air coolers and a low-temperature radiator. Since the LT-radiator has a large frontal area and is the first cooler to be exposed to the cooling air flow, very low charge air temperatures can be obtained. This type of CAC is called indirect CAC.

In the EGR cooler, **Figure 2**, the exhaust flow component for recirculation, removed from the engine at the exhaust manifold, is cooled and then added to the charge air upstream of the intake manifold. This causes the temperature of all the intake air to be lowered, which reduces the production of NO_x. However, single stage EGR cooling as used for Euro 4 is not sufficient for Euro 5; this requires either more intensive cooling or an increased EGR rate. For the latter, in order to provide a sufficient oxygen concentration in the cylinder, it is necessary to have a higher charge pressure, which in this system is obtained using two stage turbocharging with intercooling. Two stage turbocharging enables a constant engine output to be maintained in spite of increased EGR rates, and prevents any increase in particulate emissions.

In both charge air coolers the charge air, which undergoes intense heating in each of the two compression stages, is cooled back down and some of the heat which was absorbed is transferred to the liquid coolant. In the LT-radiator this heat is then dissipated into the ambient air. This radiator is installed in the vehicle frontend, which in today's truck diesel engines is the normal location for the conventional charge air cooler, connected to the turbocharger and to the intake manifold of the engine via bulky air ducts. These ducts can be eliminated with indirect CAC, which saves space and simplifies packaging.

The indirect charge air cooler can have a very compact design thanks to its high level of efficiency (compared to a charge air-to-air cooler), and this makes it possible to place the cooler between the turbocharger and the intake manifold. This also means that the charge air ducts do not need to be diverted. The charge air pressure loss can thus be reduced by up to 50 % and the charging pressure can be increased accordingly, which both improves cylinder air filling and simplifies the gas exchange process. Both factors reduce the fuel consumption at a given output.

Dispensing with the air ducts also reduces the air volume in the system. In a 12-l diesel engine a reduction of the air volume of more than 50 % was achieved thanks to iCAC. As a result the system reacts more quickly to load changes. Unlike the situation in passenger cars, however, in commercial vehicles it is not a matter of rapidly increasing torque, but of preventing emissions, for example particulate emissions. The well-known cloud which a truck without a particulate filter produces when the driver suddenly accelerates, happens because the turbocharger cannot supply the amount of air required for full-load operation straight away. There is then not enough oxygen for full combustion of the fuel, and particulate formation briefly increases rapidly. The smaller air volume thus reduces particulate emissions into the environment or the charge build-up on the particulate filter.

The intercooling of the charge air has a positive effect on the efficiency of the second charger. The charging pressure, which today involves pressures of up to 3.6 bar in the case of single stage turbocharging, can reach values of 4 to 5 bar absolute with two stage turbocharging and intercooling. As already described,

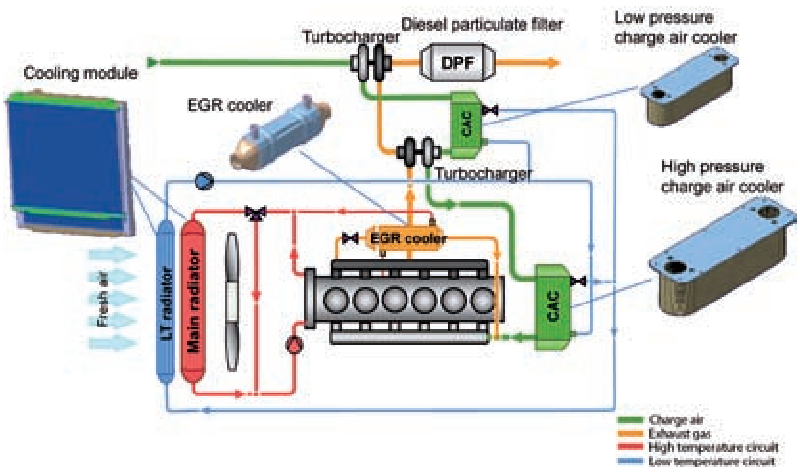


Figure 1: Engine cooling system with single stage EGR cooling and two stage turbocharging

this makes it possible to increase the EGR rates without reducing performance or increasing particulate emissions. Furthermore, a higher charging pressure theoretically opens up the following optimization opportunities:

- Increase in the power density (power per unit of displacement) of the engine. This leads either to increased engine output for the same displacement or smaller displacement for the same engine output ("downsizing"). The latter in particular has a positive effect on fuel consumption due to reduced friction in the engine.
- Increase in the excess air in the cylinder. Owing to the higher oxygen concentration in the cylinder this has a positive effect on soot formation. In other words the fuel is almost completely burned up, and less particulate matter is produced.

3.2 Engine Cooling System with Two Stage Exhaust Gas Cooling and Single Stage Turbocharging

In this system, **Figure 3**, the exhaust gas to be recirculated is first fed to an exhaust gas cooler which is cooled by the engine coolant. It is then routed to a second cooler which, as shown in the functional diagram, is located next to the charge air cooler. In this cooler the exhaust air is cooled by the ambient air. The air flow required for this is produced by the fan and/or by the airflow past the vehicle, according to the travelling speed.

Since the exhaust air is cooled in two stages in this system, resulting in lower exhaust gas temperatures, single stage turbocharging with CAC is sufficient to meet Euro 5 requirements. The charge air is cooled by the ambient air as in a conventional charge air cooler. This is why it is installed at the front of the vehicle where the ambient air flows through it. In this cooling system the exhaust gas and charge air can be brought to approximately the same temperature levels, which significantly lowers the mixing temperature upstream of the Intake manifold. In contrast to the shown separate arrangement of the charge air cooler and exhaust air cooler, this is an integrated cooler, that means a single unit comprising the charge air cooler and the exhaust air cooler.

4 Product Innovations

4.1 Integrated Exhaust Gas Cooler and Charge Air Cooler

The system consists of series-connected individual exhaust gas coolers, **Figure 4**, operating with different cooling media: engine coolant and ambient air. The air-cooled EGR cooler is integrated into the charge air cooler. This form of integration is the first of its kind worldwide.

The exhaust air cooling process: the exhaust gas flows from the cylinders are brought together in the exhaust manifold. From there some of the exhaust flows into the exhaust gas (top right, Figure 4). In this first stage of exhaust gas cooling the exhaust gas is cooled by the engine coolant. This part of the exhaust flow is then conveyed to the second stage, the air-cooled EGR cooler, integrated into the top area of the charge air cooler. When ambient air temperatures are low, the air-cooled exhaust gas cooler can be circumvented by means of a bypass in order to prevent the cooler from freezing. In both cases the exhaust gas then enters the intake manifold and the individual cylinders. It has first been mixed with the charge air cooled in the charge air cooler, so that the intake air has a uniform composition and temperature, which is important for ensuring the same combustion process in all cylinders.

In the first stage of exhaust gas cooling the exhaust gas temperature is reduced to 200 to 150 °C. In the second stage, the low temperature stage, it is then reduced to 25 to 20 K above the ambient air temperature. This lowers the temperature of the intake air overall, based on the mix ratio of charge air and exhaust gas.

The core of the air-cooled EGR cooler consists of tubes conveying exhaust gas and corrugated fins lying between them. In this cooler too, the tubes have been stamped inside to form turbulence-generating winglets.

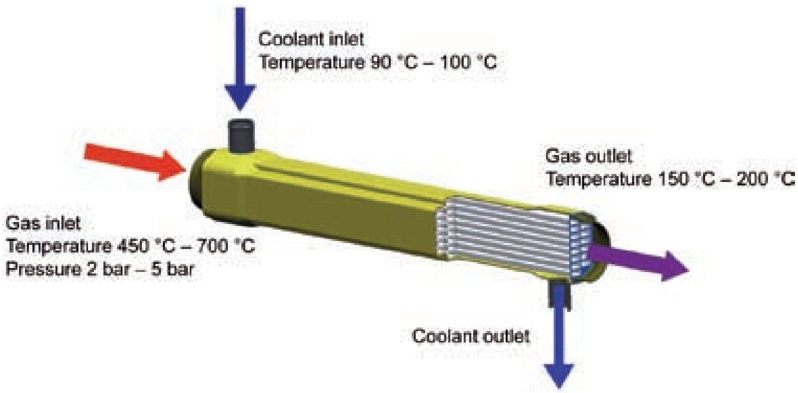


Figure 2: EGR cooler

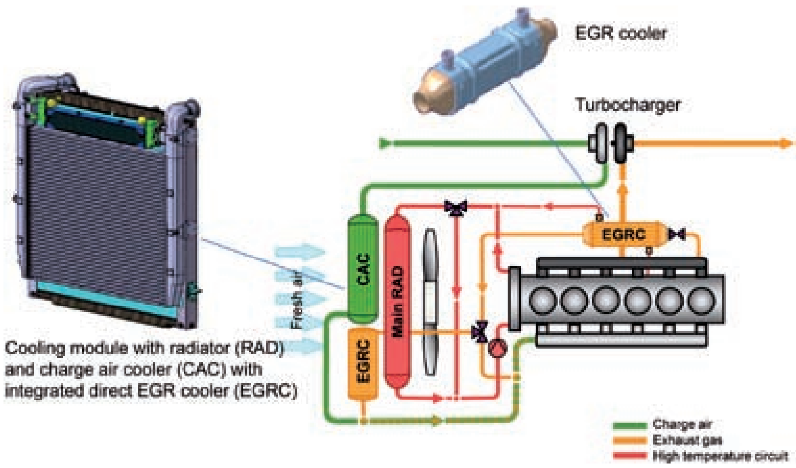


Figure 3: Engine cooling system with two stage EGR cooling and single stage turbocharging

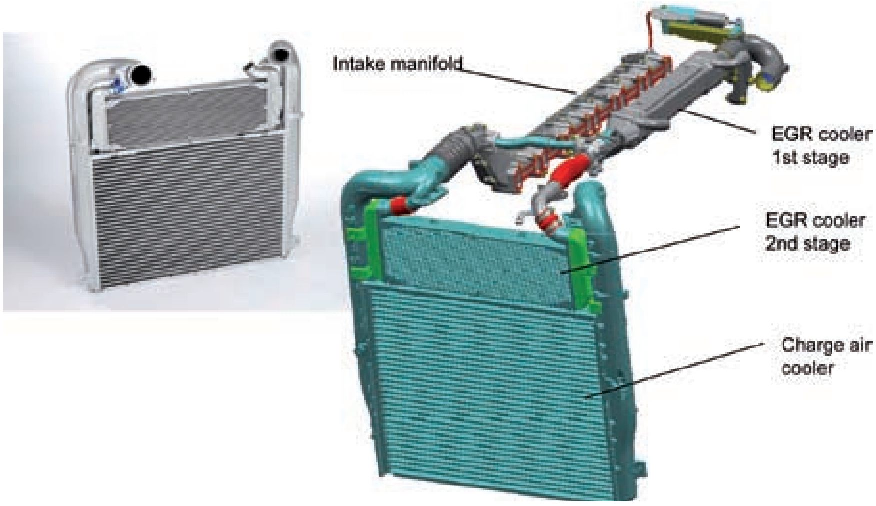


Figure 4: Two-stage EGR cooling: 1st stage coolant cooling, 2nd stage air cooling. EGR cooler integrated in charge air cooler


Figure 5: NFX 750 fan with ERS 250 fan drive

The tubes and corrugated fins are bonded together in a brazing process whereas the pipes and exhaust gas tanks are welded. The cooler consists of corrosion-resistant stainless steel tubes and corrugated fins and the exhaust gas tanks are also made of stainless steel. Features of the integrated charge air/exhaust air cooler module:
- optimized loss of pressure in exhaust gas and charge air cooler
- good mixing of charge air and exhaust gas at the mixing point
- bypass prevents freezing of the exhaust gas cooler
- no return flow of condensate into the charge air cooler
- EGR cooler is corrosion resistant.

4.2 iCAC with Integrated Thermostat

The higher EGR rates for Euro 5 compared to Euro 4 also necessitate higher charging pressures, leading to an increase in the charge air temperature. The charge air coolers used must therefore be able to withstand temperatures of more than 220 °C and pressures up to 5.1 bar absolute. Changes to the design of the charge air cooler can reduce the level of stress, which is based on the pressure and temperature load, to such an extent that the coolers are able to withstand the higher loads.

This aspect was taken into account from the outset for development work on the indirect charge air coolers and, as in the case of the charge air/EGR cooler module, development results were checked with stress analyses using the finite element method (FEM). The indirect charge air cooler is a stacked plate system comprising plates for the charge air and the cooling water ducts. Between the plates there are turbulators for the charge air and the coolant, which are optimized for heat transfer and temperature and pressure requirements.

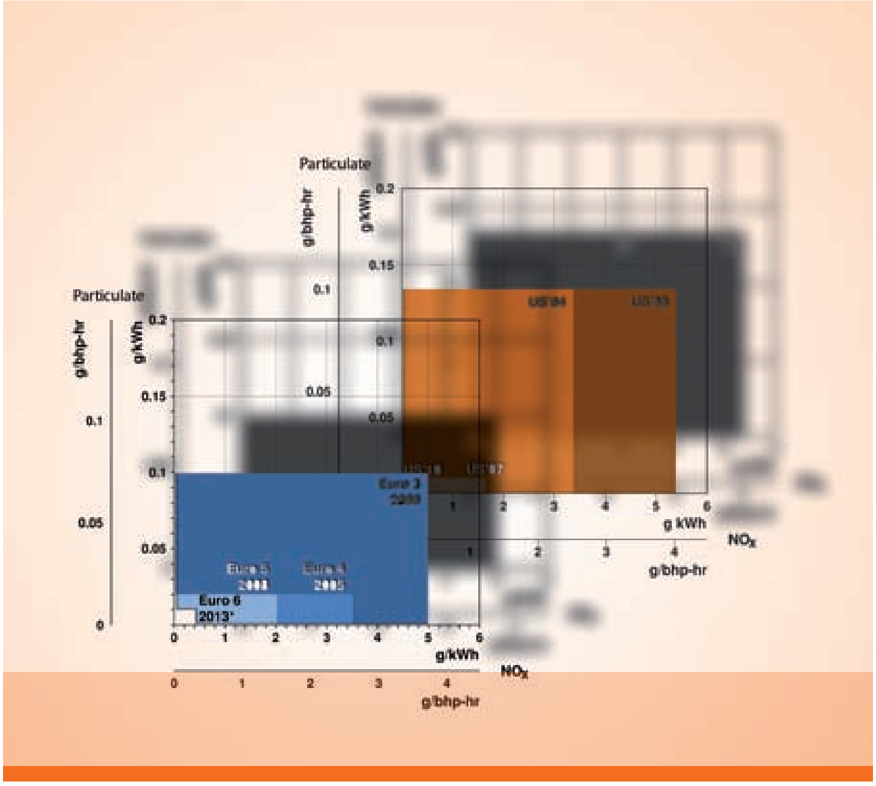
The charge air cooler is operated in a counterflow arrangement, that means the hot charge air flows in on one side and is cooled with cooling water flowing in the opposite direction. It was decided to use two intake ducts for coolant distribution. The coolant flow rate is controlled by means of temperature-controlled choke thermostats at the coolant outlet of the charge air cooler. According to the heat input from the hot charge air, the coolant flow rate is very quickly adjusted by means of fast-responding wax elements, thus avoiding the need for a complex control system.

4.3 Fan and Fan Drive

Fan output has been improved with the new NFX 750 fan, **Figure 5**. The modified blade geometry and higher number of blades (increased from eight to eleven) has boosted fan output while retaining almost the same axial construction depth as in the current series-produced model. The higher fan efficiency has also allowed the drive power to be reduced by approximately 10 % for the same mass air flow. The fan is driven by the Visco ERS 250 fan clutch. This electronically controllable clutch can transfer 40 % more torque than currently used fan drives with comparable size, along with significant improvements in controllability and dynamic clutch response. This means even more precise fan activation than before in response to the actual cooling demand, allowing the complete elimination of superfluous fan noise.

In order to cool the Visco fan drive sufficiently to accommodate its high operating range, the fan hub design has been optimally adapted to the clutch. Flow dividers and flow stabilizers in the region of the fan hub ensure that the inflowing cool air is conveyed through the cooling fins of the clutch and can then flow unobstructed through the fan blades. The result is improved cooling of the silicone fluid in the clutch and a higher slip power tolerance. Another effective means of protecting the silicone fluid in the clutch from overheating is continuous simulation of the silicone fluid temperature in the engine control unit. ■

The NO_x and particulate matter emission limits at Euro 5 and US 2007 (abbreviated as US '07) for commercial vehicle engines are a major challenge for engine and exhaust gas aftertreatment technology. US '07 is already in effect; Euro 5 will come into force in October 2008. Even more demanding technological challenges are to come: from January 2010, US 2010 (US '10) limits will apply in the USA, and the introduction of Euro 6 is expected in 2013. However, the commercial vehicle engines, which will have to meet those limits are being designed now. Behr's low temperature exhaust gas recirculation provides an appropriate technology for these engines.



NO_x Reduction Potential of Cooled Exhaust Gas Recirculation in Euro 6 Commercial Vehicles

The Author

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1 NO_x and Particulate Limits

The Table (top) shows how far the limits have reduced from Euro 3. The Euro 6 values are still to be finalized but will involve drastic reductions: in the case of nitrogen oxides (NO_x) probably by more than 80 % (from 2.0 to 0.4 to 0.7 g/kWh) and for particulate matters (PM) by more than 50 % (from 0.02 to less than 0.01 g/kWh). In the USA the forthcoming US '10 limits for NO_x are 0.20 g/bhph (approximately 0.27 g/kWh) and for PM 0.01 g/bhph (approximately 0.0134 g/kWh), Table (bottom). Of course the new limits should be met with the minimum fuel consumption penalty.

2 From Euro 5 to Euro 6

A very important step towards reducing NO_x and particulates in recent years has been the further development of the combustion system. Optimized combustion chambers, improved fuel injection

and turbocharging with charge air cooling meant that it was possible for commercial vehicle engines to comply with the Euro 3 NO_x limits without any special exhaust gas aftertreatment. However, by the time Euro 4 came into being these techniques were, for the most part, no longer sufficient. To meet the new standards additional measures were required.

In terms of internal engine measures, however, it is not possible to minimize both NO_x and PM emissions at the same time (the NO_x/PM trade-off). A viable method of achieving this goal is to minimize one component inside the engine, for example NO_x, and the other outside the engine: in this case the particulates, using a particulate filer. Conversely, reducing particulates by measures inside the engine means that NO_x reduction has to take place downstream of the engine, for example by means of the process of selective catalytic reduction, SCR.

Behr worked together with engineering consultant AVL to investigate the NO_x reduction potential of SCR and cooled exhaust gas recirculation (EGR) technology. The findings indicate that both SCR and cooled EGR are viable options for Euro 5, **Figure 1**.

Euro 6 will require enhancements to the Euro 5 technology, as illustrated in **Figure 2**. Possible concepts are:

- SCR: Selective catalytic reduction, normally combined with single stage charge air cooling.
- EGR: Cooled exhaust gas recirculation combined with two stage turbocharging with intercooling. The exhaust gas cooling also takes place in two stages: a 1st stage of high temperature exhaust gas cooling (HT-EGR), and a 2nd stage of low temperature exhaust gas cooling (LT-EGR).
- SCR plus EGR: combinations of SCR technology and cooled exhaust gas recirculation are also possible. Boosting takes place in a single stage and exhaust gas cooling is a two stage process with high and low temperature stages (HT and LT stages). Other combinations are also possible. However, the common feature in all of these is that they are complex, expensive and require considerable space.

All systems require a diesel particulate filter (DPF) to reduce PM emissions.

3 Selective Catalytic Reduction

The SCR technology already used in Euro 4 and Euro 5 systems for commercial vehicles is based on the addition of urea in the form of an aqueous solution (Adblue) to the exhaust gas flow. Hydrolysis of the urea produces ammonia, a NO_x reducing agent which converts the NO_x into steam and nitrogen in a special catalytic converter. The complete exhaust gas aftertreatment system in this case consists of a diesel oxidation catalytic converter (DOC), a DPF, a hydrolysis catalytic converter (HC), a SCR catalytic converter (SCR cat) and trap catalytic converter (TC), and the Adblue tank and a metering unit.

However, the extremely low Euro 6 and US '10 limits probably cannot be met with catalytic NO_x reduction alone. This is because of the new test cycles for measuring the emissions. Instead of the ETC (European Transient Cycle) currently specified, for Euro 6 it is likely that the new WHTC (World Harmonized Transient Cycle) will be used. This cycle results in lower engine speed and load overall and, therefore, lower exhaust gas temperatures.

However, low exhaust gas temperatures reduce the generation of ammonia from the urea solution. Additionally, at low temperatures the catalytic converter also loses some of its efficiency. Thus the

Table: NO_x and particulate emission limits for heavy duty trucks (> 3.5 t) for Europe (top) and the USA (bottom)

Phase	Introduction date	NO_x [g/kWh]	Particulate [g/kWh]	Test cycle
Euro 3	October 2000	5.0	0.10 (0.16)	ESC (ETC), ELR
Euro 4	October 2005	3.5	0.02 (0.03)	ESC (ETC), ELR
Euro 5	October 2008	2.0	0.02 (0.03)	ESC (ETC), ELR
Euro 6*	2013	0.4 – 0.7	0.01	WHTC, WHSC

ESC: European Steady State Cycle
ETC: European Transient Cycle
WHSC: World Harmonized Steady State Cycle
ELR: European Load Response Test
WHTC: World Harmonized Transient Cycle
Values in parenthesis: ETC
Introduction date for new type approvals; for all type approvals normally one year later
Limit values for CO and HC not shown here
* Euro 6 not defined specifically, decision expected in 2008

Phase	Introduction date	NMHC + NO_x [g/bhp-hr]	NO_x [g/bhp-hr]	Particulate [g/bhp-hr]	Test cycle
US'98	January 1998	-	4.0 (5.36)	0.10 (0.134)	HD-FTP
US'04	January 2004	2.5 (3.35)	-	0.10 (0.134)	HD-FTP, SET
US'07	January 2007	-	1.2 (1.61)	0.01 (0.0134)	HD-FTP, SET
US'10	January 2010	-	0.2 (0.27)	0.01 (0.0134)	HD-FTP, SET

HD-FTP: Heavy Duty Federal Test Procedure
SET: Supplemental Emission Test
Values in parenthesis: g/kWh (conversion factor: 1 g/bhp-hr = 1.34 g/kWh)
Limit values for CO and HC not shown here

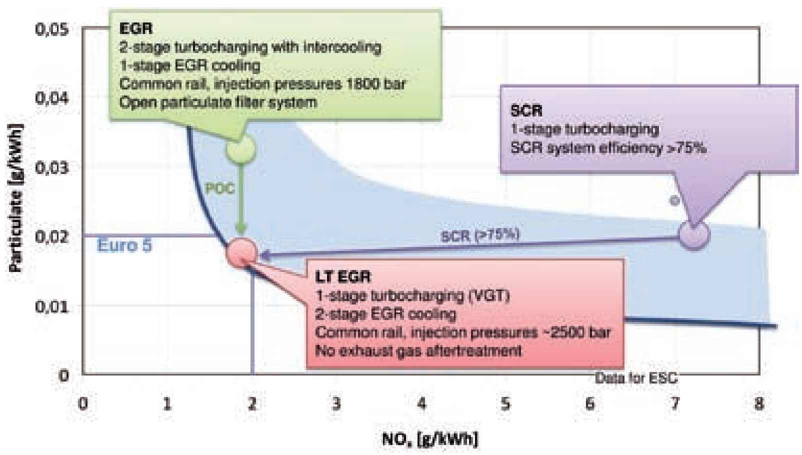


Figure 1: Technologies for Euro 5 – state of the art for the NO_x/PM trade-off

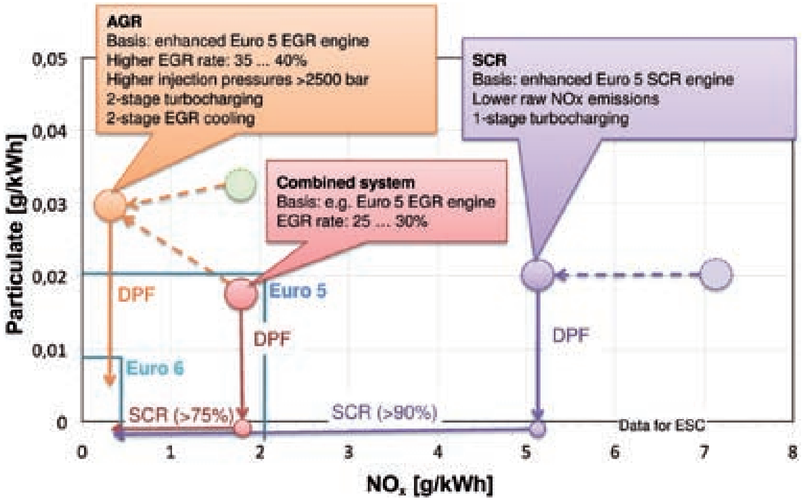


Figure 2: Technologies for Euro 6 – enhancements based on Euro 5

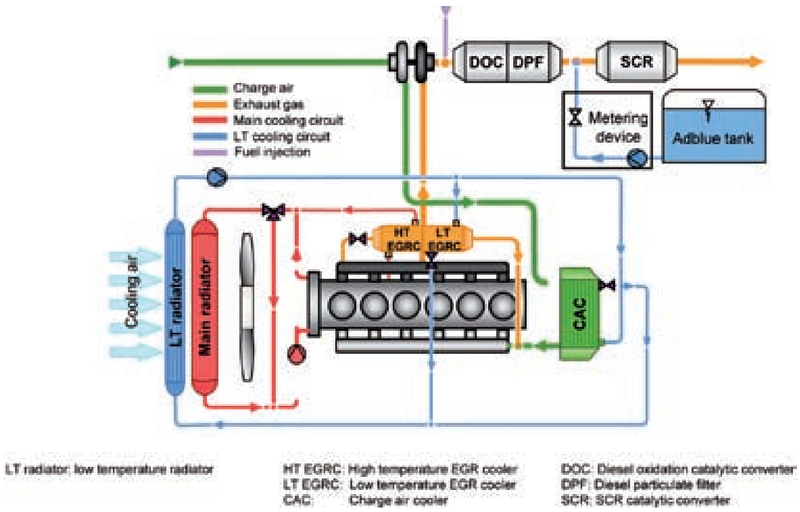


Figure 3: Combined system for Euro 6: EGR and SCR

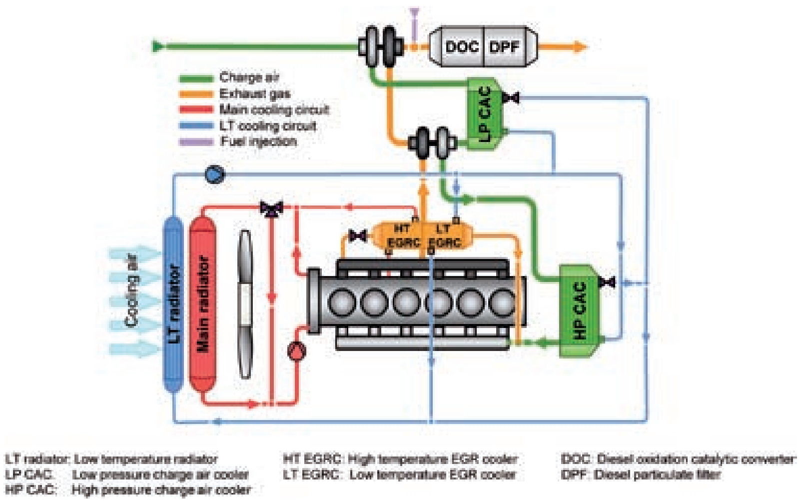


Figure 4: Potential two-stage EGR system for Euro 6

NO_x conversion rate is limited in two ways. In addition, the WHTC includes a cold test which further reduces the rate of conversion in the first part of the cycle. The resulting increase in NO_x emissions probably cannot be offset in the second hot parts of the test.

The transition from Euro 5 to Euro 6 requires an 80 % reduction in NO_x emissions. If this objective is to be achieved with selective catalytic reduction alone, the efficiency of the technology will have to be significantly increased, from around 75 % today to more than 90 %. That is not all: to offset the temperature effect from the new test cycles as described above it will be necessary to further boost the efficiency of the SCR system. Accordingly, it may be difficult to meet Euro 6 and US '10 using SCR alone.

One possible method for achieving the Euro 6 legislation would be to combine SCR and EGR technology, Figure 3. Since cooled EGR means less NO_x is produced in the engine, there is also less NO_x to be converted by catalytic reduction in the exhaust system. The drawback of this combined system, as mentioned previously, is its size and complexity.

4 Exhaust Gas Recirculation with Two Stage Cooling and Two Stage Turbocharging with Intercooling

4.1 Two Stage Exhaust Gas Cooling

Exhaust gas recirculation reduces the oxygen concentration of the cylinder charge, thus reducing the speed and temperature of combustion. Since the rate of NO_x formation is exponentially dependent on the combustion temperature, cooled exhaust gas recirculation is associated with a significant reduction in NO_x emissions. Cooling the exhaust gas also improves cylinder filling and reduces thermal stress on the engine components.

With cooled exhaust gas recirculation, some of the exhaust gas is diverted upstream from the turbocharger turbine and routed to the exhaust gas cooler via an EGR valve. In the case of two stage cooling, Figure 4, the first cooling stage is high temperature cooling (HT EGRC), the cooling medium is the coolant from the main cooling circuit, and in the second cooling stage (low temperature stage,

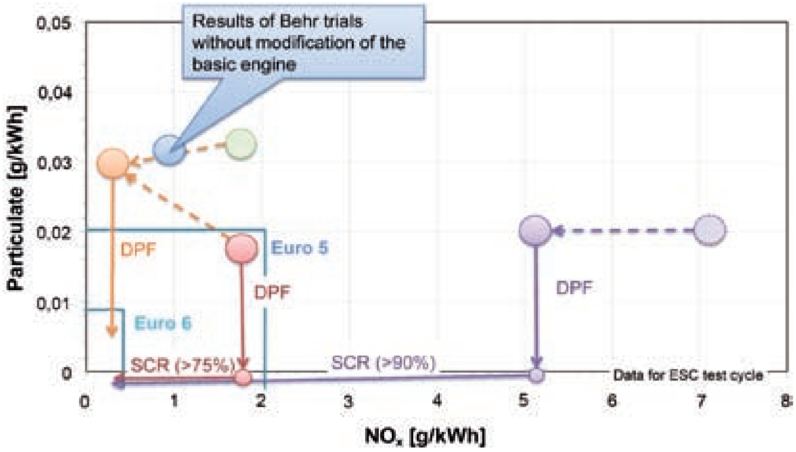


Figure 5: Potential of LT-EGR with respect to Euro 6

LT EGRC), it is the coolant from a low temperature circuit. To prevent the coolant from boiling in the first cooling stage, the exhaust gas and coolant flow in the same direction; the second stage operates in counterflow mode, which improves the cooling performance.

4.1.1 Self Cleaning of the EGR Cooler

A major advantage of two stage exhaust gas cooling – as compared with single stage cooling – is the self cleaning action of the EGR cooler and thus the stabilization of its cooling performance over the life of the cooler. This cleaning action is a consequence of the formation of condensation in the exhaust gas cooler. During the combustion, 1.26 kg of water for every 1 kg of diesel fuel is produced. Some of this steam condenses in the EGR cooler, where the condensation washes the deposits off the tubes of the cooler.

4.1.2 Cooling by Evaporation

Along with this self cleaning action, exhaust gas condensation also reduces the in-cylinder temperatures: firstly by the cooling effect from the evaporation of the charge air exhaust gas mixture and secondly by cooling due to evaporation of the intake air in the cylinder.

Cooling due to evaporation occurs when the condensate in the exhaust gas mixes with the dry charge air and evaporates. The heat required for this to happen comes from the charge air exhaust gas mixture, resulting in a fall in temperature of approximately 10 K. Because of the high dew point of steam, this cooling action occurs at high temperatures, for example 40 to 60 °C.

The exhaust gas condensate evaporates in the intake air but not completely: some water is remains and is conveyed with the intake air into the cylinders, where it evaporates in the compression phase. This second cooling effect limits the increase in the charge temperature during compression, lowering combustion temperatures and, therefore, NO_x emissions.

4.2 Two Stage Turbocharging with Intercooling

Cooling the charge air while keeping maximum cylinder pressures unchanged results in higher performance, lower fuel consumption and less formation of NO_x. In the LP and HP charge air coolers, Figure 4, the charge air, after being heated in each of the two compression stages, is cooled. The cooling of the charge air between the compressors, hence the term “intercooling”, improves the efficiency of the second compressor.

4.3 Results

In various tests Behr together with AVL has already reduced NO_x values to about 0.8 g/kWh over the test cycle. However, the optimum has still not been reached. It might be possible to reach the Euro 6 limit, which is likely to be in the region of 0.7 to 0.4 g/kWh, **Figure 5**. It should, however, be noted that low temperature EGR is likely to be successful only in combination with two stage turbocharging and advanced fuel injection systems.

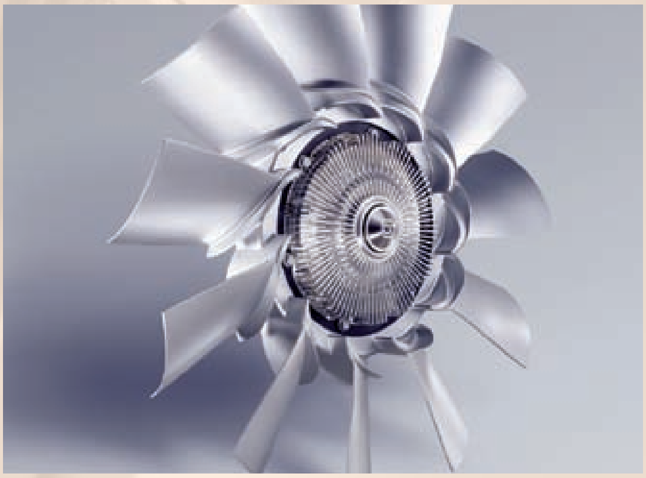
5 Conclusions

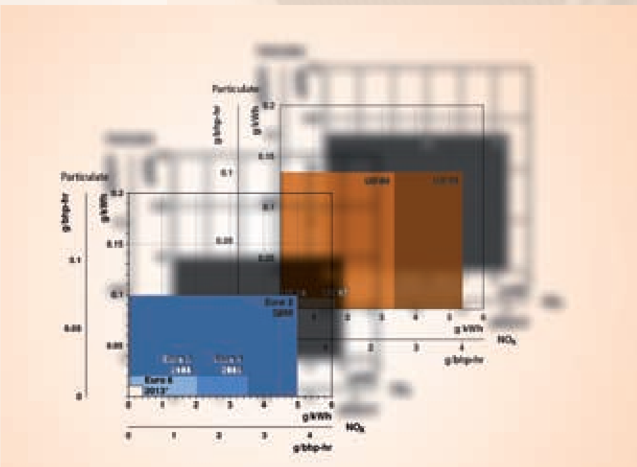
The Euro 6 and US ’10 emissions limits are unlikely to be met using SCR technology alone. Cooled exhaust gas recirculation (EGR) will be part of the emissions solution. A combination of SCR and EGR is possible but may have weight, packaging, complexity and cost penalties.

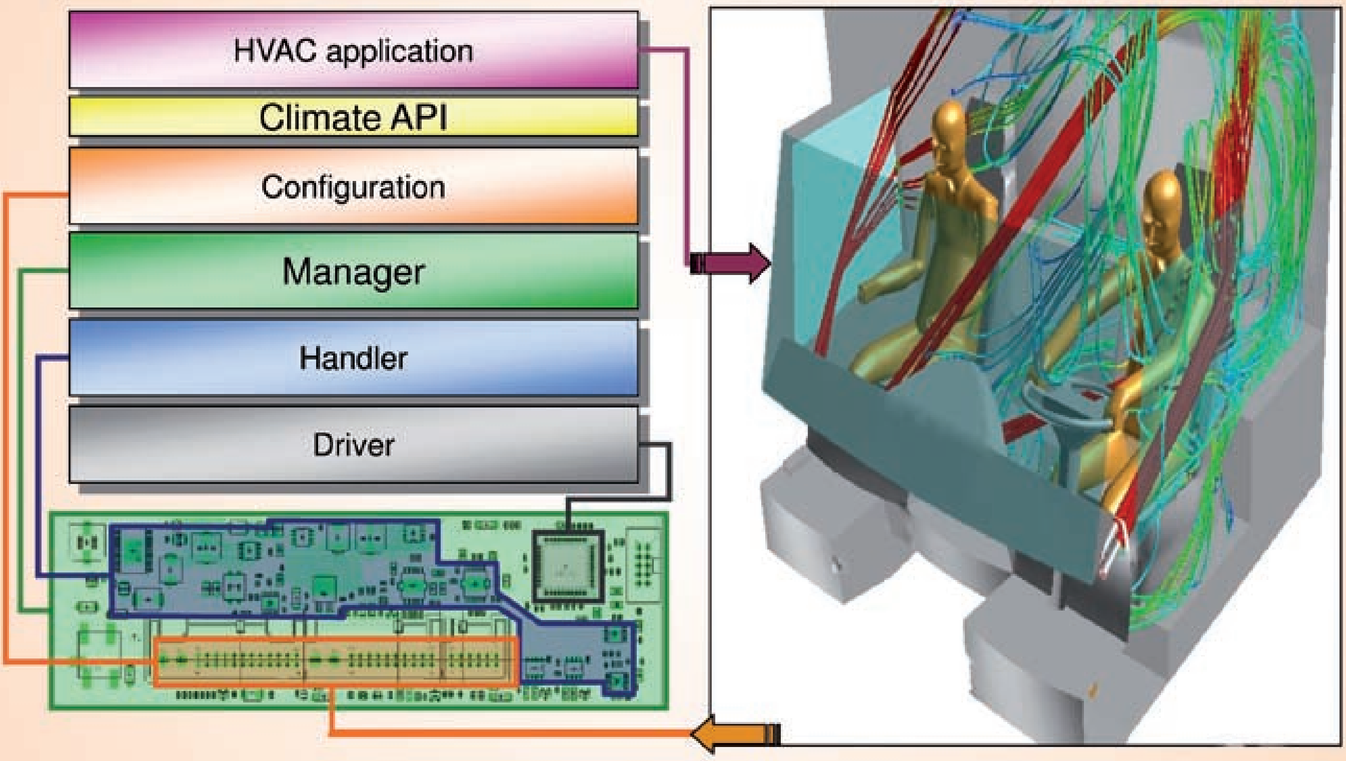
A possible solution is the two stage cooled exhaust gas recirculation process described above, combined with two stage turbocharging. This system possibly has the potential to achieve the potential Euro 6 limits. It should be noted that cooled EGR will also play a key role in enabling off-highway vehicles meet future emissions limits. ■

Special Behr

Thermal Management for Trucks







Ergonomics and Operating Concepts for Trucks

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort.

The Author

Ulrich Scheithauer is chief of product development Truckline/Thermomanagement at Behr-Hella Thermocontrol in Lippstadt (Germany).

1 Behr Hella Thermocontrol

Since the formation of BHTC as a 50/50 joint venture by the Behr and Hella groups in 1999, the company has grown rapidly and today is one of the world's leading manufacturers of control heads for HVAC systems. The product portfolio also includes control units (ECUs) for electric auxiliary heaters, blower controllers, and A/C sensors. The company counts the world's largest car and truck makers among its customers, and serves them not only from its parent plant in Lippstadt, but also from its subsidiary plants in North America, India, China, and, more recently, also in Japan. The BHTC mission is to provide "Comfort in Motion" by creating products that play a key role in ensuring optimum cimate comfort in cars and trucks.

2 Cars and Trucks: Differences in Climate Control

In recent years, there has been a sharp increase in comfort requirements for truck cabs. The driver's space is now recognized as a proper workplace. Ever more importance is accorded to the climate in the vehicle cab. Features that have long been standard in passenger cars have for some years now also been making their way into commercial vehicles. Today, no manufacturer can ignore its customers' demands for greater climate comfort. However, optimum climate comfort benefits not only the driver, but also all other road users as well: high interior air quality and a pleasant cab climate improve drivers' performance and help them to concentrate on the traffic.

Comfort is not only enjoying a pleasant climate in the driver's cab, but also the rapid response of the climate control system to changing climatic conditions. The system can thus ensure constantly mist-free windows and draft-free temperature control of the driver's workplace. The dash vents and the ventilation blowers are controlled in such a way that virtually no condensation forms on the windshield and side windows, and unwanted drafts are avoided.

Sensors measure the temperature at each of several points in the A/C system, and compensate for the influence of incoming solar radiation that falls directly onto the non-ventilated cabin temperature sensor. The climate control system can thus react quickly to changes.

Nevertheless, there are differences in the air conditioning of passenger cars and commercial vehicles that make the direct adoption of HVAC modules and control concepts from passenger cars impossible, **Figure 1**:

- A larger cab volume, and higher cabs.
- Commercial vehicles usually have a large, but vertical windshield. Compared with passenger cars, this results in less heat from solar radiation entering the cab in the middle of the day.
- Generally, the windows do not feature heat-absorbing glass comparable with that of passenger cars, and this results in a greater influx of heat when the sun is low.
- Cold outside temperatures, if they are not adequately compensated for by air conditioning, can result in an unpleasant flow of cold air at the windshield, leading to cold arms and thighs.
- Increased use as a result of ever denser traffic and frequent changes of drivers call for more user-friendly controls, that means it is important for the operator to quickly and intuitvely understand how the air conditioning system works.
- Owing to the greater movement range of the driver's seat, the operating controls must be larger and clearer in terms of their functional classification.
- The effect of the center air vent in the instrument panel is generally not so intense, owing to the greater distance to the driver.
- All system components must be designed for a longer service life.
- Today, some passenger cars have multi-zone climate control systems that must react more quickly to the changing amounts of incoming solar radiation due to the large sloping windows.
- Long-range trucks have a sleeper cab, which, in stationary operation, increasingly requires not only controllable heating, but also air conditioning; see the presentation on no-idle air conditioning.
- Passenger car platforms with high unit numbers of individual model series require specific climate control hardware and software components that are based on a standard module set. Control heads for truck air conditioning systems are also designed for platforms, but because the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software, **Figure 2**.

3 The New Climate Control System for the MAN TGX

For the design of the A/C control heads and ECUs for the air conditioning systems for the new MAN TGX, a modular concept was adopted from the outset. This concept makes a clear distinction between design and functionality.

The control head for the air conditioning system was thus integrated into the modern cockpit with significant space savings, and adapted to an individual design that meets demanding ergonomic and functional requirements. In all variants, mechanical Bowden cables from the control head to the HVAC system are dispensed with, and only six electric cables are used to connect the control head and ECU.

4 The HVAC Control Head

As the functionality of air conditioning systems increases, their operability often decreases. Especially in the case of commercial vehicles, owing to the long travel times with dense traffic, frequent changes of drivers, and the large movement range of the driver's seat, clearly identifiable and understandable controls are important.

We already provided an in-depth report on the link between operating ergo-

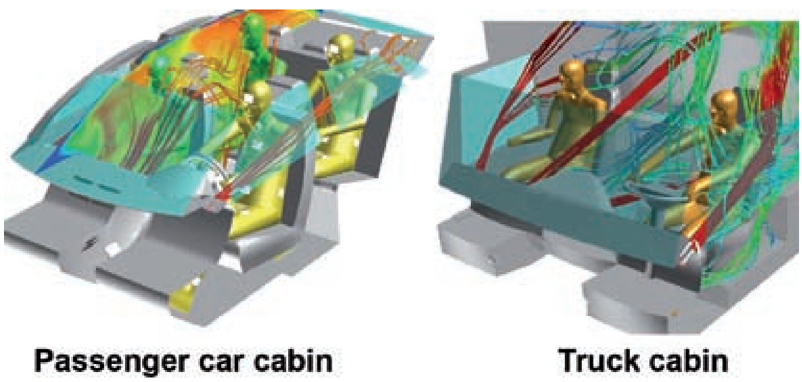


Figure 1: Cabin volume, layout and size of the windshield make up the big difference in the climate control between passenger cars and commercial vehicles

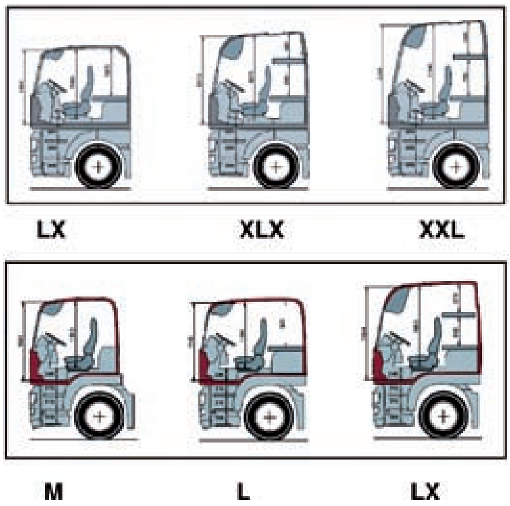


Figure 2: In commercial vehicles, the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software

nomics and traffic safety and a operability studiy carried out with the Technical University of Munich in 2007. Inadequate ergonomics lead to significant risks in traffic situations. The results show that easily recognizable symbols are based on:

- symbols/graphics
- depictions of people
- depictions of seats
- a vehicle contour to back up the symbols
- a combination of text and symbols.

Whereby symbols that are not easily recognized often contain text with no symbols, abstract symbols, or symbols that deviate from the international ISA standard.

The control heads for the MAN TGX therefore reflect the state of the art in relation to operating ergonomics, **Figure 3**.

In the fully automatic air conditioning unit, the driver selects both the desired air distribution and the blower speed by means of two control dials. The driver sets the temperature by means of two buttons, and the selected temperature is shown in a display. In the simpler heating variant, the temperature is set using the left-hand control dial, while the blower speed is changed by means of two buttons. In this A/C control head, particular importance was placed on easily understandable operation and ease of identification of the symbols for the switches and the display by both day and night. This is particularly important for trucks since they are driven for much longer periods, and also at night. It was therefore important to have highly contrasting images and clarity of symbols. This requirement was satisfied in all of the device variants by means of fail-safe LED lights, high-quality plastics technology for the operating buttons, and lasered symbols. In this way, with backlit symbols, no light can escape from the button control panel. Drivers receive an unambiguous acknowledgement from the system via the display in all control head variants, and can thus give their full attention to the traffic.

In the automatic mode of the fully automated system, the blower output temperature adjusts itself independently according to the vehicle's boundary conditions.

All the necessary settings for the air conditioning in the driver's cab and the sleeper cab in the new MAN TGX und TGS vehicles can be operated using a maximum of ten buttons and two control dials. One control head is therefore used to control both the driving and stationary operation. A second control head in the rear is therefore not necessary.

In order to ensure that the device has a long service life and is robust, and requires no maintenance, a non-ventilated interior temperature sensor (ITOS), **Figure 4**, was also used instead of the customary ventilated interior temperature sensor. The cab temperature is measured using the robust and maintenance-free sensor, and this is compensated for by means of a customized control system taking into account the incoming solar radiation, and also the heating of the device itself.

5 The Air Conditioning ECU

In the MAN TGX, a standardized air conditioning ECU was used for the first time. Behr and BHTC are thus responding to customers' demands for ever-smaller packaging dimensions of the control head and an individual design of the instrument panel with maximum control functionality.

For the climate control, a functional separation of the ECU and the A/C control head was selected, **Figure 5**. The heart of the ECU is a printed circuit board of modular construction and of standard dimensions. Thanks to the standard printed circuit board, the dimensions of

Figure 3: The control heads for the MAN TGX / TGL reflect the state of the art in relation to operating ergonomics

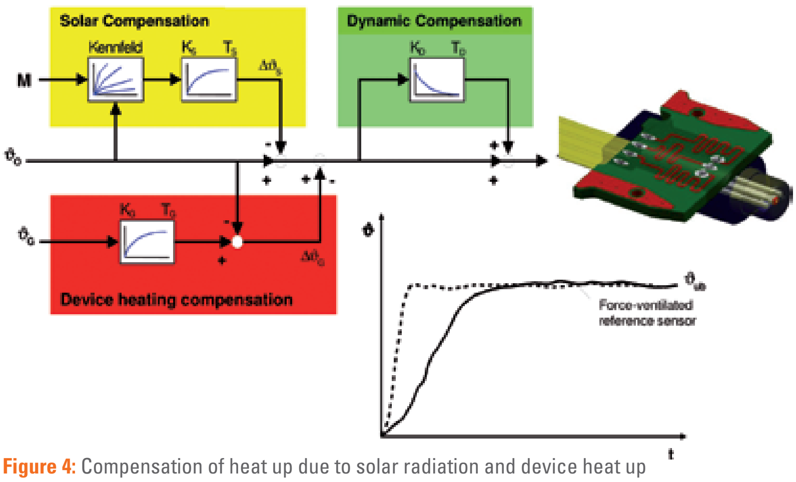


Figure 4: Compensation of heat up due to solar radiation and device heat up

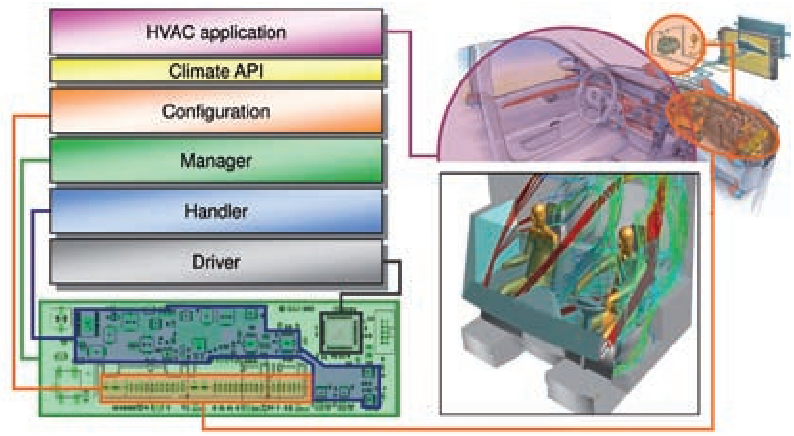


Figure 5: Architecture of the standardized air conditioning ECU – separation of function and design

the ECU and the connector plug are identical for all variants.

The ECU is installed in the vehicle in such a way that the HVAC module and ECU form a functional unit with short electrical connections. A mechanical coupling between the control head and the HVAC module is no longer required. In addition to the preferred mounting position on the HVAC module, other mounting locations in the vehicle are, in principle, also possible.

The open architecture and the less complex design of the control head give the customer more freedom in the design of the instrument panel in the vehicle than before, and better use is made of the existing space envelope. Other variants adapted to the customer's requirements can be obtained only by means of a different assembly and different programming of the processor. This reduces the development outlay required for variants, and cuts costs. The ECU is also flexible in terms of the interface to the customer's preferred data bus format.

6 Summary

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort. Operation of the air conditioning unit must respect ergonomic considerations, so that drivers take advantage of all of the capabilities of the A/C system on the one hand, and are not distracted from the traffic by its operation on the other.

With the unit's design and operating concept, BHTC has satisfied the increasing demands for an A/C control head that is modern, efficient, and at the same time user-friendly.

Whatever the initial climatic conditions at the start of the journey, or however they change during the trip, the climate control system always ensures consistently comfortable and draft-free air conditioning, and thus avoids any additional stress for the driver.

A climate control system that is functionally and ergonomically designed using state-of-the-art processes thus plays a key part in reducing the stress on drivers, and, thanks to the comfortable cab conditions, helps them stay relaxed in every traffic situation. ■

Non-idle Air Conditioning for Enhanced Road Safety and Reliability

Transportation of freight by truck is very important for the functioning of the economy and society. As the driving condition of the driver plays a key role in this, it is essential to provide adequate thermal and acoustic comfort during rest periods. A non-idle A/C system that provides air conditioning both during journeys as well as during rest periods and when the windows are closed, improves driver recuperation. The driver is thus better able to concentrate and feels fitter and more refreshed.

The Author

Dr. Lubens Simon is chief of commercial vehicle climate systems development at the Behr GmbH & Co. KG in Stuttgart-Feuerbach (Germany).

1 Introduction

Transportation of freight by truck plays a key role in the functioning of the economy and society in all Western countries. It is even more important that this transportation takes place in a safe, reliable, and eco-friendly manner, and that it is cost-efficient. Drivers play a key role in achieving this: their health, ability to perform and to concentrate, in short: their driving condition. In order to maintain this condition at a high level for the entire duration of the journey, drivers require a workplace that is ergonomically designed and has a pleasant cab climate.

This involves a high level of thermal and accoustic comfort, which is important not only during the journey itself, but also when any stops are made, whether they are voluntary or involuntary. The thermal comfort is particularly important in driver rest periods, because otherwise the degree of recuperation is reduced. This applies especially to the sleeping phase, since drivers who are not well-rested pose a danger to themselves and to other road users. The infamous "miscrosleep," one of the greatest causes of accidents, is primarily due to inadequate or unrestorative sleep. Non-idle air conditioning, that cools the cabin also during the rest periods with windows closed, enhances the thermal comfort of the driver and thus his ability to concentrate.

2 Driver Survey on the Use of Non-idle A/C Systems

In 2006, Behr surveyed 500 truck drivers from different countries with different vehicles at a total of six rest areas along Germany's main highways. The aim of the survey was to find out how the drivers use the cab as a living space, and what the requirements of this living space are (with a focus on air conditioning), and also what the future requirements of the market are, and which product strategy can be developed from this information.

After this general questioning, 16 drivers were selected for a longer interview. These people formed a representative market cross-section of long-distance drivers who had a non-idle A/C system.

It was found that the great majority of the drivers believe that a non-idle air conditioning unit is important. Around 90 % of the drivers who did not have this sort of system in their vehicle would choose to have one. Since only one fifth of all long-distance trucks are equipped with non-idle vehicle air conditioning, there is a very high market potential. By contrast: parking heating systems are found in all heavy-duty trucks. A summary of the driver's views: Non-idle air conditioning systems ...

- ... are used in a similar way as parking heaters, and are valued just as highly by drivers
- ... are nevertheless available commercially only at a market level of 20 %
- ... are perceived as improving drivers' personal safety
- ... avoid engine idling, and thus prevent fuel consumption and engine wear
- ... should provide air conditioning at night for up to ten hours, and for up to two hours during the day with incoming solar radiation
- ... should provide automatically controlled air conditioning for the entire cab
- ... should not require any servicing or any initial activation.

According to this information, non-idle air conditioning systems have a high market potential. From these and further results of the survey, the following specifications have been provided:

Non-idle air conditioning systems should ...

- ... cool the cab during overnight stops for up to ten hours and for up to two hours during the day (even with strong incoming solar radiation)
- ... provide draft-free cooling of the entire cab (not only the space above the bed)
- ... have automatic temperature control
- ... be reliable and easy to operate
- ... not require any maintenance; the charging of the energy storage devices (cooling battery or battery pack) should occur automatically
- ... be interfaceable with an automatic fresh air supply.

The requested hours of operation and performance can be fulfilled by electrical systems. Also, roof units will fulfill the expectations on non-idle a/c units. The non-idle air conditioning systems currently available on the market are still highly inadequate compared with what drivers want in terms of both their technology and their performance. In order to satisfy all of the requirements of the users, Behr has set itself the following additional design objectives for non-idle air conditioning systems:

- a low current draw in order to allow battery pack operation
- installation in existing roof openings for aftermarket applications
- satisfy truckmakers' installation requirements, specifically in terms of quality, durability and reliability and integration into the operating system architecture.

On the basis of these design objectives, an electric non-idle air conditioning unit

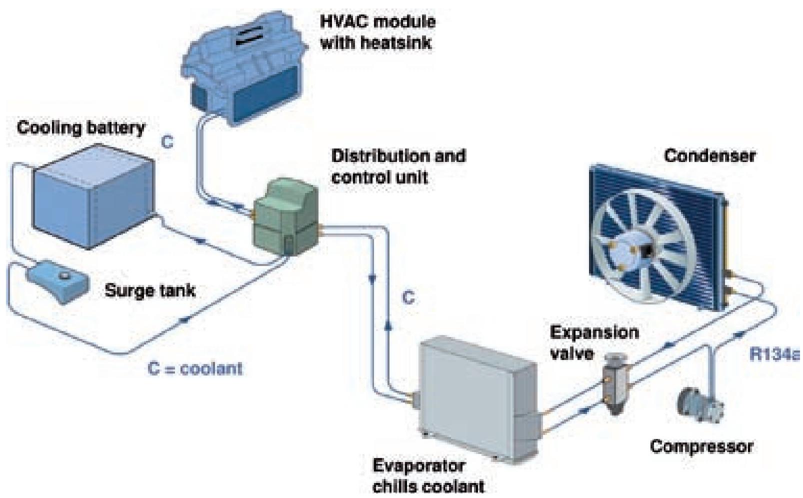


Figure 1: System diagram of the non-idle air conditioning with cooling battery from MAN

in the form of a roof unit was designed and constructed as a demonstration model, in addition to the non-idle air conditioning system with a cooling battery that is already in series production. Design of a rear wall unit is currently under way.

3 Technical Features of the Cooling Battery System

The non-idle air conditioning system with a cooling battery is fully integrated in the vehicle, and replaces the conventional engine-driven air conditioning system. The system has a secondary circuit **Figure 1**. In the charging phase, a conventionally operated refrigerant circuit intensely cools a liquid refrigerant in a special evaporator. This coolant, controlled by the distribution unit, cools both the heat sink in the HVAC module as well as the contents of the cooling battery, which therefore freezes. The heat sink replaces the conventional evaporator in the HVAC module; it cools the cab air during the journey, and during breaks in the journey. In the non-idle A/C system, the refrigerant circuit is in the resting state. By means of the circulating refrigerant, the heat from the vehicle cab is slowly transferred to the cooling battery, where the frozen content of the cooling battery is liquefied. The system with the cooling battery is fitted as standard in the heavy commercial MAN vehicles TGA (since 2003) and the more recent TGX from MAN (since 2007).

4 Technical Features of the Roof Air Conditioning Unit

This plug-in 24-V unit can either be factory fitted or retroffited on the aftermarket. The unit is made up of an electrically operated, conventional refrigerant circuit that essentially consists of a compressor, condenser with fan, receiver, blower, and evaporator with expansion device, **Figure 2**. These components are housed in a single module that projects into the roof opening of the vehicle. Inside the cab, a screen allows drivers to see only the air inlet and the air outlet openings, and the control head. **Figure 3** shows a cross-section through the roof unit installed in the ceiling of the cab, and how it works.

The unit is operated with recirculated air. Control of the fresh air supply is integrated in the control system of the engine-driven air conditioning unit. For the power supply, in addition to the starter batteries, an additional battery pack, for example consisting of lead-gel batteries, must be provided in the vehicle. Some of today's systems are, in fact, powered by conventional starter batteries, but these are not really suitable for operating non-idle air conditioning systems because they are designed to deliver a high current over a short period of time. The non-idle air conditioning system must, however, be supplied with power over several hours. In a nine-hour operation, the battery is almost completely drained, and thus needs to be recharged. If a starter battery was frequently charged and drained, its capacity would quickly be reduced even after 15 such cycles to under 40 %. Starter batteries are therefore unsuitable for this application.

Lead-gel batteries, by contrast, are cycle-proof, that means they can be repeatedly recharged to a high capacity.

The roof air conditioning unit provides sufficient power to air-condition the cab, even with incoming solar radiation during the day. The two-hours-per-day period of operation determined from the driver survey is not, however, the critical value for the battery pack, but instead night operation of up to ten hours. In the case of an average power consumption of the unit of only 400 W, this would require, for example, a battery pack with four standard size traction batteries. The low power consumption of 400 W is the result of the system's exceptionally high efficiency.

Figure 4 uses measured values from the Behr climatic wind tunnel to show the course of air conditioning at night

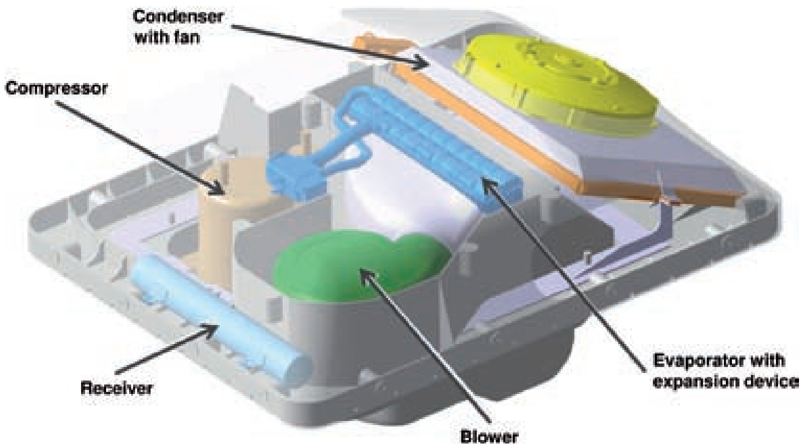


Figure 2: Schematic depiction of the electrial roof air conditioning unit

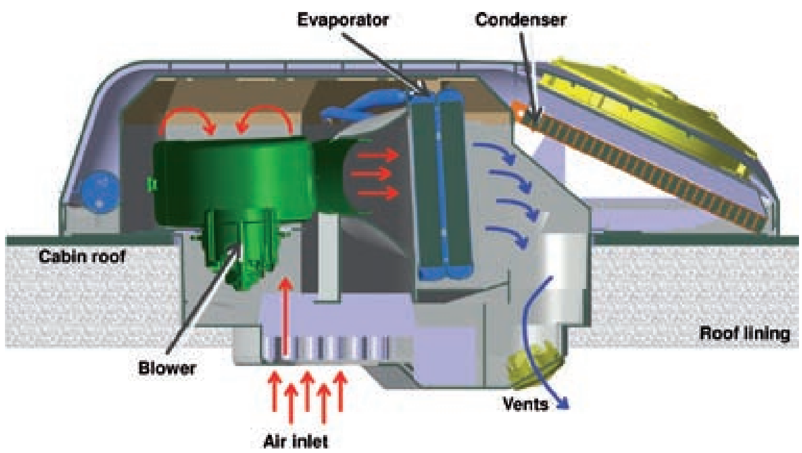


Figure 3: Side view of the electrial roof air conditioning unit

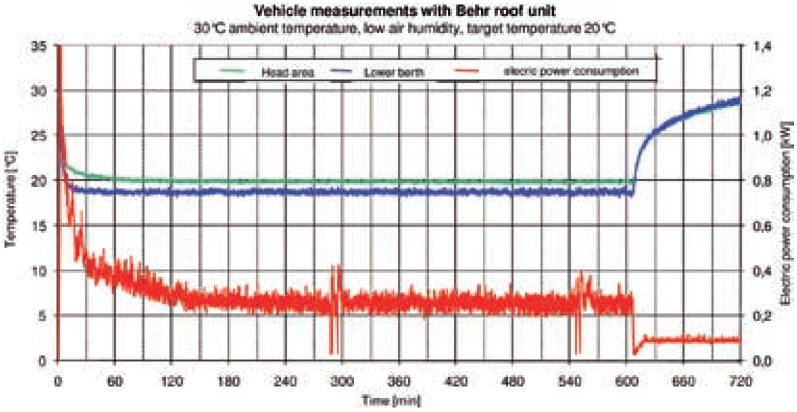


Figure 4: Cool down and power consumption of the electrial roof air conditioning unit at night

with an outside temperature of 30 °C. The target temperature of 20 °C is very quickly achieved and maintained, thanks to the temperature control over the ten hours. The power consumption is almost always less than 400 W.

5 Advantages of the Electrical System

The electrical system has two advantages over the system with the cooling battery: for one thing, drivers can access the cooling capacity at almost any time, because the batteries can store the power supplied by the generator for a long time. They therefore do not need to plan the charging or even to initiate it, since this happens automatically. During the journey, the battery pack is then constantly maintained in the fully charged state. In the system with the cooling battery, the charging of which is initiated manually, it is not possible to exclude the possibility that the driver may one day forget to initiate the charging, or may initiate it too late. If cooling is then required, there may be no or insufficient cooling capacity available. This point was also mentioned in the driver survey, which then also led to the call for an automatic charging of the cooling battery or battery pack.

The second advantage of the electrical system is that, with the battery pack for the non-idle air conditioning unit, additional electrical devices can also be operated, for example a television, computer, microwave oven, or coffee machine. Because the starter battery need not be used to do this, it therefore cannot be drained accidentally.

6 Behr's Development Capacity

As an original equipment manufacturer and systems supplier of passenger car and truck air conditioning units, Behr designs not only the HVAC modules, but also the control heads and associate software, working with joint venture companies such as Behr-Hella Thermocontrol (BHTC). This calls for expertise in the communication processes in the vehicle and for close collaboration with the vehicle manufacturers, for example for the construction of an interface between the engine-driven and non-idle air conditioning systems. Such an interface is required, for example, when the fresh air supply to the cab is to be taken over by the engine-powered A/C system instead of the non-idle air conditioning unit. This is particularly desirable when the truck's engine-driven A/C system is equipped with active carbon filters. In this case, the cab is supplied with filtered, gas-free air that increases drivers' safety when they are asleep. Generally, the fresh air is supplied at intervals, activated, for example, by a timer. The timed control saves battery power, but still guarantees an adequate supply of fresh air.

7 Summary

Non-idle air conditioning systems have considerable market potential, comparable with that of parking heaters, with which almost 100 % of long distance trucks are equipped. Behr's electrical units satisfy all relevant performance requirements, and have proven to provide a higher cooling capacity and higher efficiency than all comparable systems. A further advantage of the Behr units is their reliability, because the system components were designed specifically for use in trucks, and are sourced from series production of vehicle air conditioning units. ■

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US '10 envisages another drastic reduction in NO_x emissions for commercial vehicles.

Measures for Satisfying Future Exhaust Emissions Standards in Special-purpose Vehicles

1 Behr Industry

When Behr Industry was founded in 1990, the objective was to cater to special markets in the engine cooling and air conditioning sectors. The justification for this was that technical and legal requirements were made with respect to the components and systems of off-highway vehicles that were completely different from those for the passenger car and commercial vehicle markets – requirements that cannot be satisfied by simple modification of an existing component or of an existing system.

The split of Behr Industry and Behr GmbH & Co. KG essentially reflects our customer structure, since Behr's customers often operate in different market segments, and under different names. Today, Behr Industry is active in the markets for buses, heavy-duty engines, railway vehicles, aircraft, construction and agricultural vehicles, electronics, military products, and gensets (that means diesel-engine driven generators for generating electricity). The most important requirements are:

- The smaller production volumes or even single unit productions, also mean, that different development procedures, manufacturing technologies, and logistic concepts are necessary.
- The Euromot, EEV, and Tier X legislation governing emissions and CO_2

emissions is very similar to the Euro 5/6 and US 'XX standards from the car and truck vehicle sectors – only time-displaced by about three years.
– Other constraints on cooling requirements, installed position, and the available installation space.
– In the special-purpose vehicles, the components and systems are exposed to different stresses: fouling through mud, dust, and fibers results in different focuses for the development of heat exchangers. In some shipbuilding applications, cooling takes place using the seawater itself. The corrosive action of the saltwater is countered with special stainless steel.

2 Small-scale Series Production

For example for buses, small-scale series production specifically means annual volumes of approximately 500 to 3000 units. In the case of railway vehicles, the figure can be as low as just five to 100 units per year. Behr Industry must therefore use other processes for manufacturing radiators and coolers and for assembling complete cooling systems. Semi- or fully automatic production equipment can be used only rarely, and the costs of die-casting or functional plastic components often cannot be redeemed, owing to the high capital costs involved. Flexible systems are called for that require little or no capital expenditure; however, these demand higher manual production outlay and highly skilled manufacturing staff. Behr Industry also endeavors to carry over products or components from high-volume series production and integrate them (for example buses and tractors) in order to take advantage of the cost benefits of large-scale series production. This significantly reduces R&D expenditure, validation requirements, and the risk of failures in the field.

Behr Industry also employs the general Behr production standards and development tools and tests and develops its products in the test facility of the parent company, and uses the same simulation tools (FE analyses, CFD calculations, BISS). This makes the development of new products specifically catering to special market requirements efficient and competitive.

3 Exhaust Emissions Standards

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US 10 envisages another drastic reduction in NO_x emissions for commercial vehicles. The corresponding standard for the off-highway sector is Euromot stage IIIB / Tier IV A, and will come into effect approximately three years after Euro 5 / US 10. The limits for NO_x and particulate emissions are not much different from those of commercial vehicles: Euromot stage IIIB envisages a reduction of nitrogen oxide emissions to 2 g/kWh, and of particulate emissions to 0.025 g/kWh (Euro 5 specifies 2.0 NO_x and 0.2 PM).

The exhaust emissions standards for off-highway vehicles in the USA are similar. The standards that are similar to the US07 and US10 standards are the Tier 4a and Tier 4b standards, which will come into effect at the same time as Euromot stage IIIB, that means three years later.

In the bus market, we find a special situation; here, the EEV (Enhanced Environmental Friendly Vehicle) preliminary standard was introduced. EEV is not a mandatory limit, but rather a voluntary standard that is virtually no different from Euro 5 in terms of the limits on NO_x and particulate emissions. EEV engines essentially already satisfy the Euro 5 standard that will be in force from 2009. The environmental awareness of the bus operators, in particular in large cities, leads to their voluntarily complying with special limits as per EEV.

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In order to comply with the exhaust emissions regulations and to save fuel in off-highway applications, as in the case of commercial vehicles, systems such as cooled exhaust gas recirculation or two-stage turbocharging are used, **Figure 1**. Here, too, this similarly leads to increasingly complex cooling systems every time the exhaust emissions laws are tightened further. Higher charge air temperatures and pressures and quantities of heat in the coolant call for new solutions for heat exchanger design. The integration of cooled exhaust gas cooling and indirectly cooled charge air requires considerable systems expertise in order to be able to guarantee the necessary cooling within the special constraints of the off-highway market.

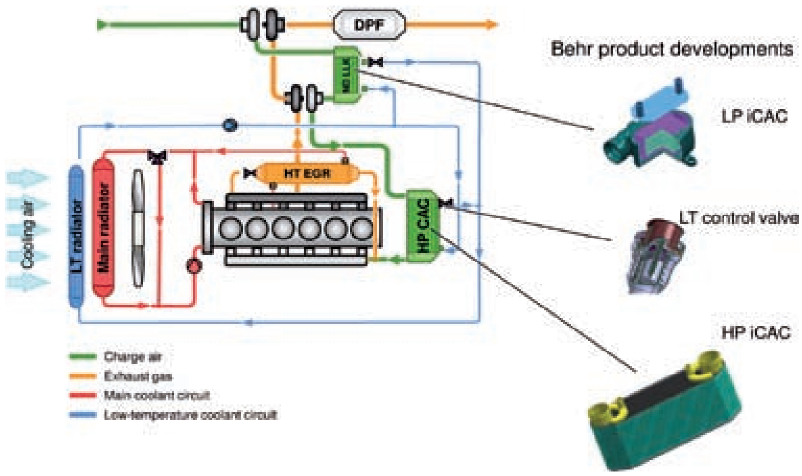

Figure 1: Schematic representation of a two stage turbocharging with indirekt charge air cooling

4 Fouling

A distinctive feature of special-purpose vehicles is their use in very different areas of application: mines, fields, rails, water, construction sites, forests, or garbage dumps. Fouling on the external surface through which cooling air passes thus takes very different forms. Sand, dust, oils, pollen, leaves, plant debris, grass, litter, and many other soiling agents in every possible combination accumulate on the air side inside the radiator and between the fins, Figure 2. This leads to a higher air-side pressure loss and restricts the flow of cooling air. The radiator can no longer provide the desired cooling power to the engine, and engine performance decreases accordingly.

Here, conventional radiators with louvered corrugated fins cannot be used. Behr Industry has developed special cooling air fins specifically for these applications. Unlike conventional fins, these do not have any louvered structure on their surface; instead, they are flat or corrugated. In car or truck radiators, these louvers serve to improve heat transfer between the cooling air and the cooling water, because the air does not pass through the fins in a laminar flow, but instead turbulence is produced on the louvers, Figure 3. However, a lot of dirt particles collect on these louvers that cannot be removed by using compressed air, for example. If there are no louvers, dirt particles can be blown away against the direction of flow.

In order to understand the mechanisms of fouling and to draw the appropriate technical conclusions, Behr Industry has been working closely with a number of institutes for several years. Figure 4 and Figure 5 show the results of tests on different cooling air fins that were realized in collaboration with the ILK Dresden (Institute of Air Handling and Refrigeration Technology in Dresden). These tests investigated to what extent the pressure drop on the cooling air side is dependent on the dust concentration and the fin used. It was found that the flat fin has the smallest pressure drop. Figure 5 shows the results of similar tests, but under more realistic conditions using fibers as the fouling agent. A flat fin, a staggered fin and a louvered fin were exposed to fibers during usage and the cooling air side pressure drop was measured over time. After a predetermined cycle had been completed, the fins were cleaned with compressed air. It is observed that the pressure drop in the louvered fin is worse after every cleaning cycle compared with the flat fin and the fin with deep corrugations. This is because fibers penetrate deep inside the fins, and, in the louvered fin in particular, can then no longer be removed. Therefore, over time, the radiator with the louvered fins becomes clogged up, and can no longer be cleaned.

Of course, the efficiency of the radiator decreases with the soiling of the louvers. Together with our customers, we must therefore arrive at a compromise between the prevention of fouling and the performance density of the radiator.

Furthermore, the arrangement of the individual coolers (radiator, charge air cooler, etc.) can play a role in minimizing the susceptibility of the cooling module to fouling. In conventional radiators, the individual radiators are arranged one behind the other ("face to face"). The problem here is that dirt particles may pass through the first radiator and become caught in the second one. For cleaning, the cooling module would have to be dismantled. To avoid this, the radiators can be arranged next to one another ("side by side"), so that all of the faces can be cleaned from the outside. Alternatively, the frame of the cooling module can also be designed to swing open, in order to facilitate cleansing of the second radiator, Figure 6.

5 Systems Expertise

All of these requirements must be implemented for a small market that individually caters to specific customers. Behr Industry provides not just the coolers and

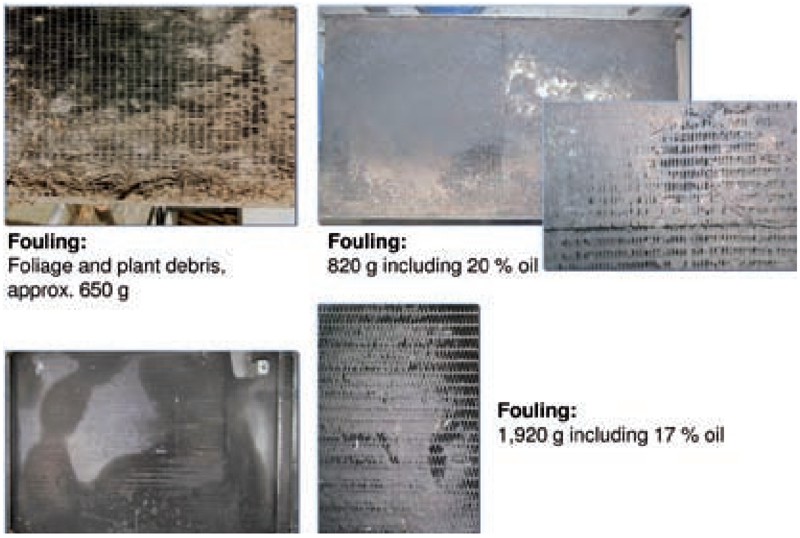

Figure 2: Representative examples of different foulings as found in off-highway applications

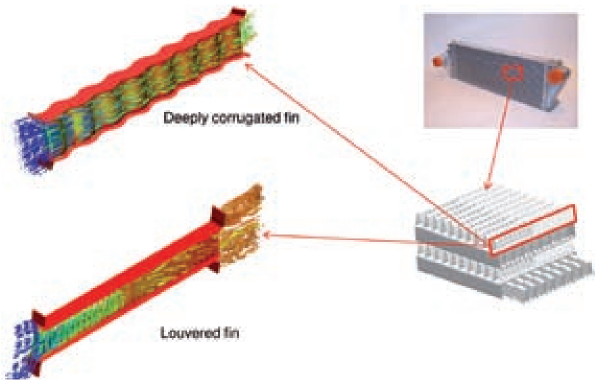

Figure 3: Comparison of a deeply corrugated fin and a louvered fin

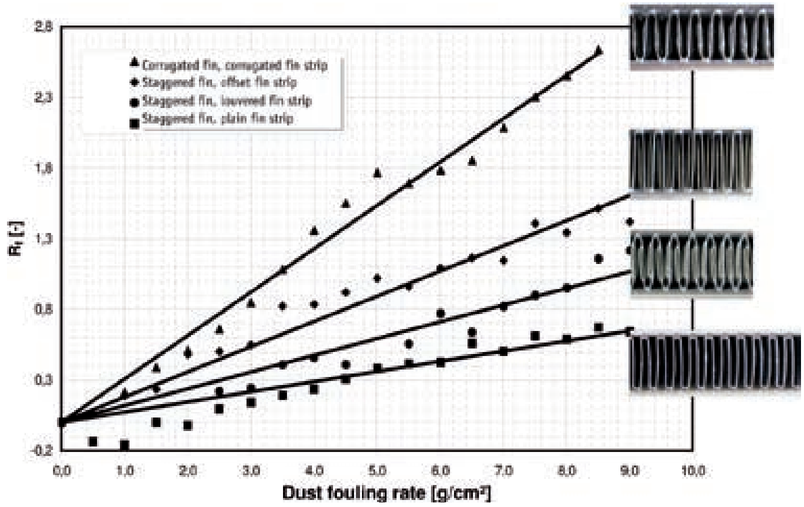

Figure 4: Fouling: Impact of dust on the pressure loss in coolers. Investigations performed by ILK Dresden on behalf of Behr Industry

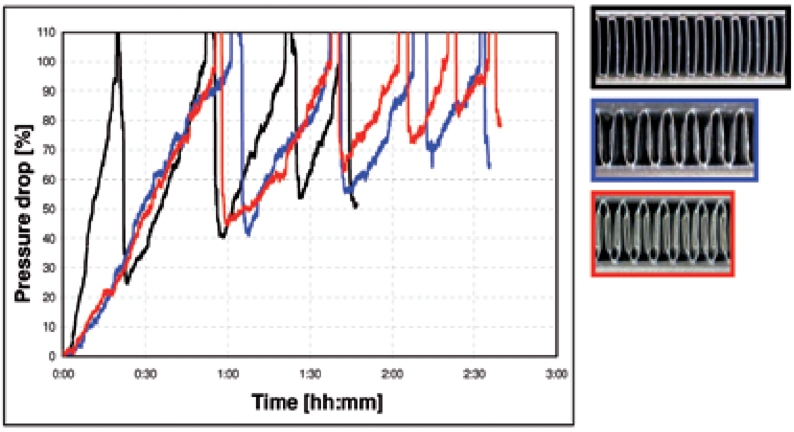

Figure 5: Fouling: Impact of fibers on the pressure loss in coolers and the regeneration of coolers with different fins. Investigations performed by ILK Dresden on behalf of Behr Industry

Figure 6: Solutions designed to prevent fouling – cooling module for city bus featuring swing-out device (top); tractor cooling module with coolers arranged in parallel on the cooling air side (bottom)

radiators themselves, but also complete ready-to-install cooling systems including the radiator/coolers, fan, fan drive, frame, and, if required, also the surge tank, water and oil pumps, and level controller, working in close collaboration with and for its customers.

When solving these technological problems, Behr Industry calls on Behr‘s development methods, results and products, as they are described in the article “Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles”. Behr Industry uses this technology and adapts it to suit the respective engines and the needs of the different special markets. Indirect charge air cooling is standard in commercial vehicle engines. The corresponding indirect charge air coolers are designed in a stacked plate construction. Behr Industry adapts the coolers for a potentially higher engine power. This can be achieved with a simple scaling, that means an increase in the quantity of stacked plates, for example, or, alternatively, by means of bundling existing EGR coolers when there are very high quantities of exhaust gas in the cooled exhaust gas recirculation, for example.

Because the installation position of the engines in special-purpose vehicles is often different from that of conventional commercial vehicles, adapting the components for the new installation position represents another challenge.

If the installation position changes, very often the air ducting on the cooling module or the position of the surge tank relative to the radiator changes as well. In conventional applications, the cooling air is routed from the front through the radiator into the engine compartment. In railway vehicle applications, for example, this is often not possible, owing to the installation position. In roof units, the air is conveyed laterally through the radiator and leaves the module at the top. In other locomotive applications, the radiators are located at the bottom of the module and the cooling air is routed through the assembly from the top to the bottom. If the surge tank for the cooling medium cannot be mounted above the radiator, technical solutions such as an anti-cavitation tank or two-chamber system must be found in order to ensure that the cooling circuit remains free of air. ■

In recent years Behr has made such progress in developing cooled exhaust gas recirculation and iCAC systems that commercial vehicle manufacturers now have at their disposal reliable, production-ready solutions for reducing NO_x emissions. When used in combination, these new cooling systems can meet Euro 5 emissions requirements without the need for a special exhaust treatment process such as selective catalytic reduction (SCR).

Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles

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1 Introduction

And in contrast to SCR, these innovations do not require any additional operating agent. When they are used in conjunction with the latest engine and injection technology there is no increase in fuel consumption, and they also allow weight reductions at comparable costs. Further benefits are the flexibility of application of these new solutions, and their high potential for further development to meet Euro 6 requirements.

2 Emissions Standards and Reduction Technologies

2.1 Emissions Standards

Since 1992 (Euro 1), the limits for heavy trucks have been brought down in five stages, including some very drastic reductions. Since 2000 (Euro 3) emission limits for NO_x have been reduced from 5 to 2 g/kWh, and particulate emissions from 0.10 to 0.02 g/kWh. In percentage terms this corresponds to a 60 % reduction for NO_x and 80 % for particulates.

2.2 Exhaust Air Cooling and Charging

The exhaust gas recirculation process is essentially based on the fact that the exhaust gas has a higher heat capacity and a lower oxygen content than air. This causes the combustion temperatures in the cylinder to fall. The cooling of the exhaust gas and the charge air makes the temperatures drop even further. Because NO_x formation is an exponential function of these temperatures, a combination of cooled exhaust gas recirculation and turbocharging with CAC was able to meet the Euro 4 limits. Compliance with the stricter requirements of Euro 5 requires either an increase in EGR rates or a reduction in exhaust gas and charge air temperatures. The single stage EGR with two stage turbocharging plus intercooling, and two stage cooled EGR with single stage turbocharging are available for this purpose.

3 Engine Cooling Systems for Euro 5

Over the last few years Behr has been investigating how the increasingly stringent limits can be met by improving engine cooling. In particular, efficient charge air and exhaust gas cooling have a positive effect both on NO_x formation in the combustion chamber and fuel consumption. The newly developed production-ready engine cooling systems for Euro 5 and their components are described below, including comparisons with the SCR system.

3.1 Engine Cooling System with Single Stage Exhaust Gas Cooling and Two Stage Turbocharging

Figure 1 is a functional schematic of such a cooling system. It comprises an exhaust gas cooler which is cooled by the engine coolant, and a low temperature (LT) cooling circuit which contains two charge air coolers and a low-temperature radiator. Since the LT-radiator has a large frontal area and is the first cooler to be exposed to the cooling air flow, very low charge air temperatures can be obtained. This type of CAC is called indirect CAC.

In the EGR cooler, **Figure 2**, the exhaust flow component for recirculation, removed from the engine at the exhaust manifold, is cooled and then added to the charge air upstream of the intake manifold. This causes the temperature of all the intake air to be lowered, which reduces the production of NO_x. However, single stage EGR cooling as used for Euro 4 is not sufficient for Euro 5; this requires either more intensive cooling or an increased EGR rate. For the latter, in order to provide a sufficient oxygen concentration in the cylinder, it is necessary to have a higher charge pressure, which in this system is obtained using two stage turbocharging with intercooling. Two stage turbocharging enables a constant engine output to be maintained in spite of increased EGR rates, and prevents any increase in particulate emissions.

In both charge air coolers the charge air, which undergoes intense heating in each of the two compression stages, is cooled back down and some of the heat which was absorbed is transferred to the liquid coolant. In the LT-radiator this heat is then dissipated into the ambient air. This radiator is installed in the vehicle frontend, which in today's truck diesel engines is the normal location for the conventional charge air cooler, connected to the turbocharger and to the intake manifold of the engine via bulky air ducts. These ducts can be eliminated with indirect CAC, which saves space and simplifies packaging.

The indirect charge air cooler can have a very compact design thanks to its high level of efficiency (compared to a charge air-to-air cooler), and this makes it possible to place the cooler between the turbocharger and the intake manifold. This also means that the charge air ducts do not need to be diverted. The charge air pressure loss can thus be reduced by up to 50 % and the charging pressure can be increased accordingly, which both improves cylinder air filling and simplifies the gas exchange process. Both factors reduce the fuel consumption at a given output.

Dispensing with the air ducts also reduces the air volume in the system. In a 12-l diesel engine a reduction of the air volume of more than 50 % was achieved thanks to iCAC. As a result the system reacts more quickly to load changes. Unlike the situation in passenger cars, however, in commercial vehicles it is not a matter of rapidly increasing torque, but of preventing emissions, for example particulate emissions. The well-known cloud which a truck without a particulate filter produces when the driver suddenly accelerates, happens because the turbocharger cannot supply the amount of air required for full-load operation straight away. There is then not enough oxygen for full combustion of the fuel, and particulate formation briefly increases rapidly. The smaller air volume thus reduces particulate emissions into the environment or the charge build-up on the particulate filter.

The intercooling of the charge air has a positive effect on the efficiency of the second charger. The charging pressure, which today involves pressures of up to 3.6 bar in the case of single stage turbocharging, can reach values of 4 to 5 bar absolute with two stage turbocharging and intercooling. As already described,

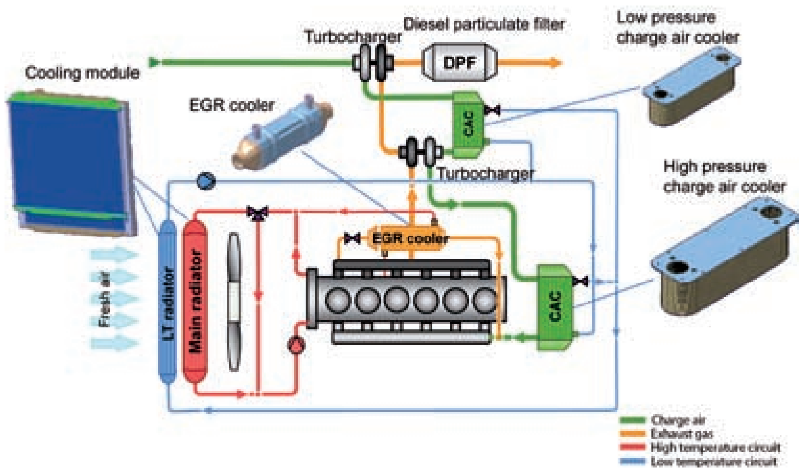


Figure 1: Engine cooling system with single stage EGR cooling and two stage turbocharging

this makes it possible to increase the EGR rates without reducing performance or increasing particulate emissions. Furthermore, a higher charging pressure theoretically opens up the following optimization opportunities:

- Increase in the power density (power per unit of displacement) of the engine. This leads either to increased engine output for the same displacement or smaller displacement for the same engine output ("downsizing"). The latter in particular has a positive effect on fuel consumption due to reduced friction in the engine.
- Increase in the excess air in the cylinder. Owing to the higher oxygen concentration in the cylinder this has a positive effect on soot formation. In other words the fuel is almost completely burned up, and less particulate matter is produced.

3.2 Engine Cooling System with Two Stage Exhaust Gas Cooling and Single Stage Turbocharging

In this system, **Figure 3**, the exhaust gas to be recirculated is first fed to an exhaust gas cooler which is cooled by the engine coolant. It is then routed to a second cooler which, as shown in the functional diagram, is located next to the charge air cooler. In this cooler the exhaust air is cooled by the ambient air. The air flow required for this is produced by the fan and/or by the airflow past the vehicle, according to the travelling speed.

Since the exhaust air is cooled in two stages in this system, resulting in lower exhaust gas temperatures, single stage turbocharging with CAC is sufficient to meet Euro 5 requirements. The charge air is cooled by the ambient air as in a conventional charge air cooler. This is why it is installed at the front of the vehicle where the ambient air flows through it. In this cooling system the exhaust gas and charge air can be brought to approximately the same temperature levels, which significantly lowers the mixing temperature upstream of the Intake manifold. In contrast to the shown separate arrangement of the charge air cooler and exhaust air cooler, this is an integrated cooler, that means a single unit comprising the charge air cooler and the exhaust air cooler.

4 Product Innovations

4.1 Integrated Exhaust Gas Cooler and Charge Air Cooler

The system consists of series-connected individual exhaust gas coolers, **Figure 4**, operating with different cooling media: engine coolant and ambient air. The air-cooled EGR cooler is integrated into the charge air cooler. This form of integration is the first of its kind worldwide.

The exhaust air cooling process: the exhaust gas flows from the cylinders are brought together in the exhaust manifold. From there some of the exhaust flows into the exhaust gas (top right, Figure 4). In this first stage of exhaust gas cooling the exhaust gas is cooled by the engine coolant. This part of the exhaust flow is then conveyed to the second stage, the air-cooled EGR cooler, integrated into the top area of the charge air cooler. When ambient air temperatures are low, the air-cooled exhaust gas cooler can be circumvented by means of a bypass in order to prevent the cooler from freezing. In both cases the exhaust gas then enters the intake manifold and the individual cylinders. It has first been mixed with the charge air cooled in the charge air cooler, so that the intake air has a uniform composition and temperature, which is important for ensuring the same combustion process in all cylinders.

In the first stage of exhaust gas cooling the exhaust gas temperature is reduced to 200 to 150 °C. In the second stage, the low temperature stage, it is then reduced to 25 to 20 K above the ambient air temperature. This lowers the temperature of the intake air overall, based on the mix ratio of charge air and exhaust gas.

The core of the air-cooled EGR cooler consists of tubes conveying exhaust gas and corrugated fins lying between them. In this cooler too, the tubes have been stamped inside to form turbulence-generating winglets.

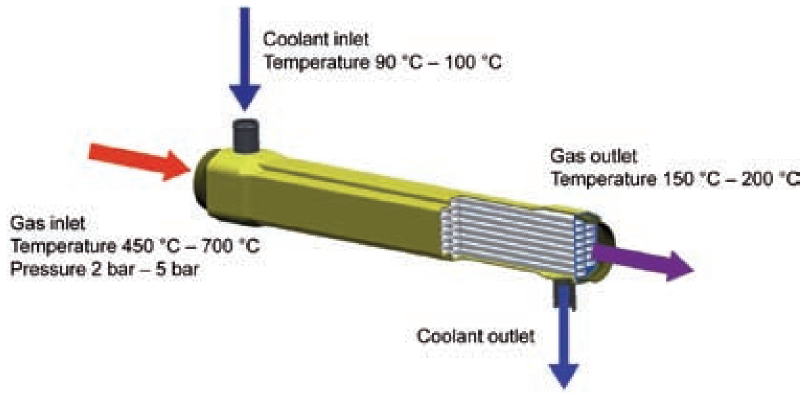


Figure 2: EGR cooler

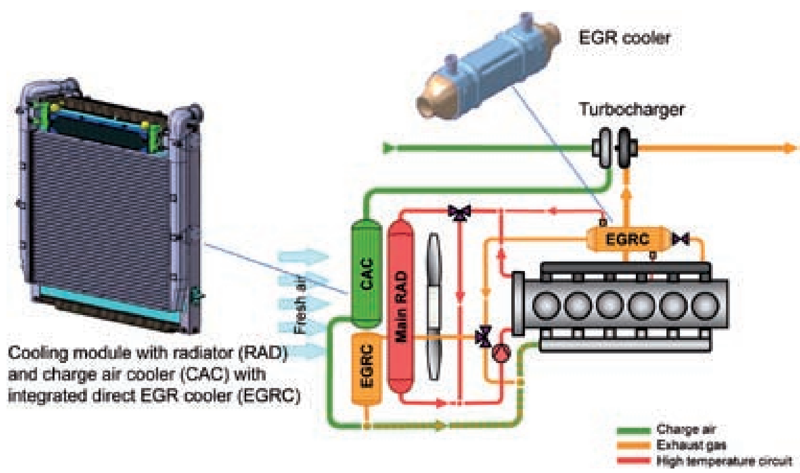


Figure 3: Engine cooling system with two stage EGR cooling and single stage turbocharging

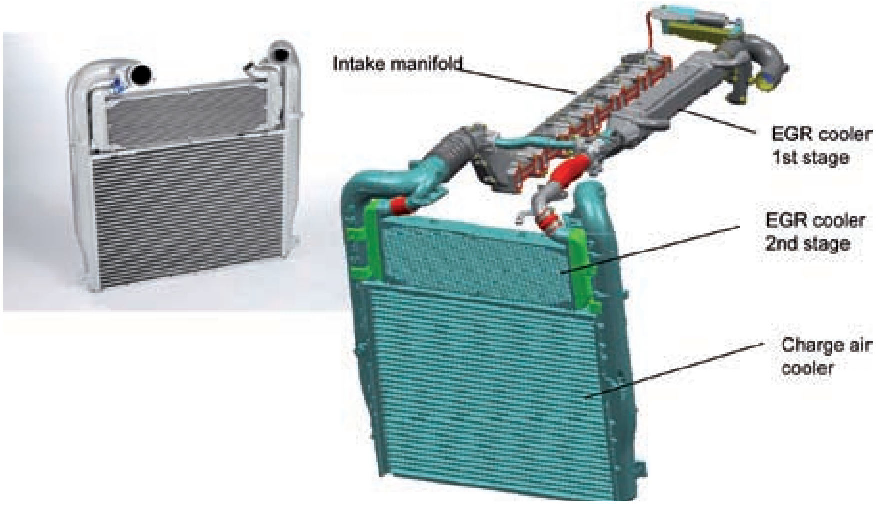


Figure 4: Two-stage EGR cooling: 1st stage coolant cooling, 2nd stage air cooling. EGR cooler integrated in charge air cooler

Figure 5: NFX 750 fan with ERS 250 fan drive

The tubes and corrugated fins are bonded together in a brazing process whereas the pipes and exhaust gas tanks are welded. The cooler consists of corrosion-resistant stainless steel tubes and corrugated fins and the exhaust gas tanks are also made of stainless steel. Features of the integrated charge air/exhaust air cooler module:

- optimized loss of pressure in exhaust gas and charge air cooler
- good mixing of charge air and exhaust gas at the mixing point
- bypass prevents freezing of the exhaust gas cooler
- no return flow of condensate into the charge air cooler
- EGR cooler is corrosion resistant.

4.2 iCAC with Integrated Thermostat

The higher EGR rates for Euro 5 compared to Euro 4 also necessitate higher charging pressures, leading to an increase in the charge air temperature. The charge air coolers used must therefore be able to withstand temperatures of more than 220 °C and pressures up to 5.1 bar absolute. Changes to the design of the charge air cooler can reduce the level of stress, which is based on the pressure and temperature load, to such an extent that the coolers are able to withstand the higher loads.

This aspect was taken into account from the outset for development work on the indirect charge air coolers and, as in the case of the charge air/EGR cooler module, development results were checked with stress analyses using the finite element method (FEM). The indirect charge air cooler is a stacked plate system comprising plates for the charge air and the cooling water ducts. Between the plates there are turbulators for the charge air and the coolant, which are optimized for heat transfer and temperature and pressure requirements.

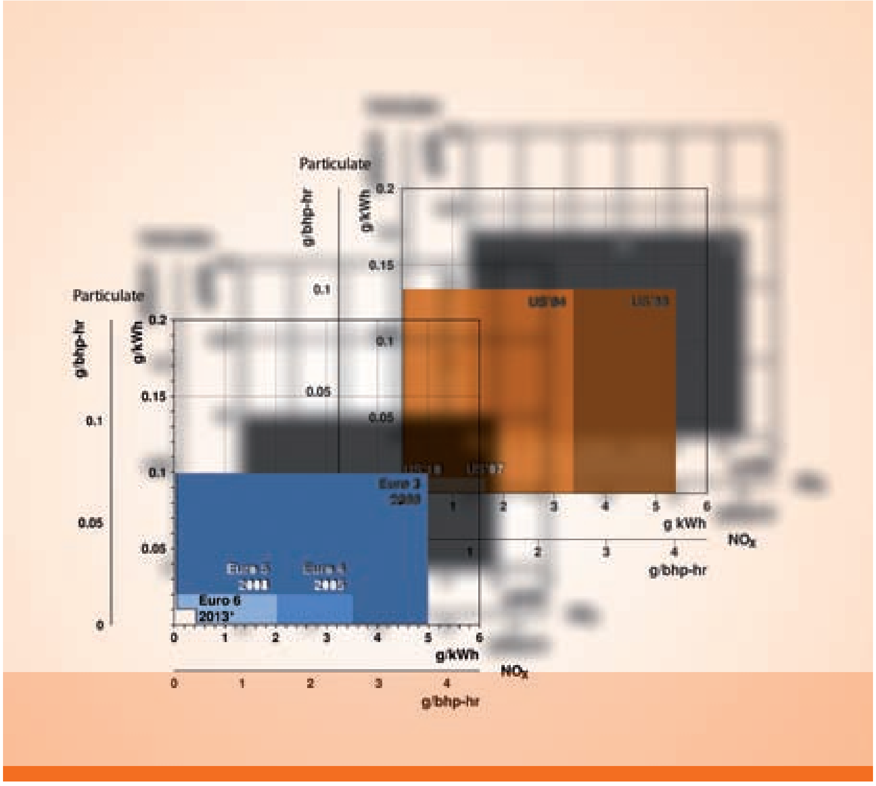
The charge air cooler is operated in a counterflow arrangement, that means the hot charge air flows in on one side and is cooled with cooling water flowing in the opposite direction. It was decided to use two intake ducts for coolant distribution. The coolant flow rate is controlled by means of temperature-controlled choke thermostats at the coolant outlet of the charge air cooler. According to the heat input from the hot charge air, the coolant flow rate is very quickly adjusted by means of fast-responding wax elements, thus avoiding the need for a complex control system.

4.3 Fan and Fan Drive

Fan output has been improved with the new NFX 750 fan, **Figure 5**. The modified blade geometry and higher number of blades (increased from eight to eleven) has boosted fan output while retaining almost the same axial construction depth as in the current series-produced model. The higher fan efficiency has also allowed the drive power to be reduced by approximately 10 % for the same mass air flow. The fan is driven by the Visco ERS 250 fan clutch. This electronically controllable clutch can transfer 40 % more torque than currently used fan drives with comparable size, along with significant improvements in controllability and dynamic clutch response. This means even more precise fan activation than before in response to the actual cooling demand, allowing the complete elimination of superfluous fan noise.

In order to cool the Visco fan drive sufficiently to accommodate its high operating range, the fan hub design has been optimally adapted to the clutch. Flow dividers and flow stabilizers in the region of the fan hub ensure that the inflowing cool air is conveyed through the cooling fins of the clutch and can then flow unobstructed through the fan blades. The result is improved cooling of the silicone fluid in the clutch and a higher slip power tolerance. Another effective means of protecting the silicone fluid in the clutch from overheating is continuous simulation of the silicone fluid temperature in the engine control unit. ■

The NO_x and particulate matter emission limits at Euro 5 and US 2007 (abbreviated as US '07) for commercial vehicle engines are a major challenge for engine and exhaust gas aftertreatment technology. US '07 is already in effect; Euro 5 will come into force in October 2008. Even more demanding technological challenges are to come: from January 2010, US 2010 (US '10) limits will apply in the USA, and the introduction of Euro 6 is expected in 2013. However, the commercial vehicle engines, which will have to meet those limits are being designed now. Behr's low temperature exhaust gas recirculation provides an appropriate technology for these engines.



NO_x Reduction Potential of Cooled Exhaust Gas Recirculation in Euro 6 Commercial Vehicles

The Author

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1 NO_x and Particulate Limits

The Table (top) shows how far the limits have reduced from Euro 3. The Euro 6 values are still to be finalized but will involve drastic reductions: in the case of nitrogen oxides (NO_x) probably by more than 80 % (from 2.0 to 0.4 to 0.7 g/kWh) and for particulate matters (PM) by more than 50 % (from 0.02 to less than 0.01 g/kWh). In the USA the forthcoming US '10 limits for NO_x are 0.20 g/bhph (approximately 0.27 g/kWh) and for PM 0.01 g/bhph (approximately 0.0134 g/kWh), Table (bottom). Of course the new limits should be met with the minimum fuel consumption penalty.

2 From Euro 5 to Euro 6

A very important step towards reducing NO_x and particulates in recent years has been the further development of the combustion system. Optimized combustion chambers, improved fuel injection

and turbocharging with charge air cooling meant that it was possible for commercial vehicle engines to comply with the Euro 3 NO_x limits without any special exhaust gas aftertreatment. However, by the time Euro 4 came into being these techniques were, for the most part, no longer sufficient. To meet the new standards additional measures were required.

In terms of internal engine measures, however, it is not possible to minimize both NO_x and PM emissions at the same time (the NO_x/PM trade-off). A viable method of achieving this goal is to minimize one component inside the engine, for example NO_x, and the other outside the engine: in this case the particulates, using a particulate filer. Conversely, reducing particulates by measures inside the engine means that NO_x reduction has to take place downstream of the engine, for example by means of the process of selective catalytic reduction, SCR.

Behr worked together with engineering consultant AVL to investigate the NO_x reduction potential of SCR and cooled exhaust gas recirculation (EGR) technology. The findings indicate that both SCR and cooled EGR are viable options for Euro 5, Figure 1.

Euro 6 will require enhancements to the Euro 5 technology, as illustrated in Figure 2. Possible concepts are:

- SCR: Selective catalytic reduction, normally combined with single stage charge air cooling.
- EGR: Cooled exhaust gas recirculation combined with two stage turbocharging with intercooling. The exhaust gas cooling also takes place in two stages: a 1st stage of high temperature exhaust gas cooling (HT-EGR), and a 2nd stage of low temperature exhaust gas cooling (LT-EGR).
- SCR plus EGR: combinations of SCR technology and cooled exhaust gas recirculation are also possible. Boosting takes place in a single stage and exhaust gas cooling is a two stage process with high and low temperature stages (HT and LT stages). Other combinations are also possible. However, the common feature in all of these is that they are complex, expensive and require considerable space.

All systems require a diesel particulate filter (DPF) to reduce PM emissions.

3 Selective Catalytic Reduction

The SCR technology already used in Euro 4 and Euro 5 systems for commercial vehicles is based on the addition of urea in the form of an aqueous solution (Adblue) to the exhaust gas flow. Hydrolysis of the urea produces ammonia, a NO_x reducing agent which converts the NO_x into steam and nitrogen in a special catalytic converter. The complete exhaust gas aftertreatment system in this case consists of a diesel oxidation catalytic converter (DOC), a DPF, a hydrolysis catalytic converter (HC), a SCR catalytic converter (SCR cat) and trap catalytic converter (TC), and the Adblue tank and a metering unit.

However, the extremely low Euro 6 and US '10 limits probably cannot be met with catalytic NO_x reduction alone. This is because of the new test cycles for measuring the emissions. Instead of the ETC (European Transient Cycle) currently specified, for Euro 6 it is likely that the new WHTC (World Harmonized Transient Cycle) will be used. This cycle results in lower engine speed and load overall and, therefore, lower exhaust gas temperatures.

However, low exhaust gas temperatures reduce the generation of ammonia from the urea solution. Additionally, at low temperatures the catalytic converter also loses some of its efficiency. Thus the

Table: NO_x and particulate emission limits for heavy duty trucks (> 3.5 t) for Europe (top) and the USA (bottom)

Phase	Introduction date	NO_x [g/kWh]	Particulate [g/kWh]	Test cycle
Euro 3	October 2000	5.0	0.10 (0.16)	ESC (ETC), ELR
Euro 4	October 2005	3.5	0.02 (0.03)	ESC (ETC), ELR
Euro 5	October 2008	2.0	0.02 (0.03)	ESC (ETC), ELR
Euro 6*	2013	0.4 – 0.7	0.01	WHTC, WHSC

ESC: European Steady State Cycle
ETC: European Transient Cycle
WHSC: World Harmonized Steady State Cycle
ELR: European Load Response Test
WHTC: World Harmonized Transient Cycle
Values in parenthesis: ETC
Introduction date for new type approvals; for all type approvals normally one year later
Limit values for CO and HC not shown here
* Euro 6 not defined specifically, decision expected in 2008

Phase	Introduction date	NMHC + NO_x [g/bhp-hr]	NO_x [g/bhp-hr]	Particulate [g/bhp-hr]	Test cycle
US'98	January 1998	-	4.0 (5.36)	0.10 (0.134)	HD-FTP
US'04	January 2004	2.5 (3.35)	-	0.10 (0.134)	HD-FTP, SET
US'07	January 2007	-	1.2 (1.61)	0.01 (0.0134)	HD-FTP, SET
US'10	January 2010	-	0.2 (0.27)	0.01 (0.0134)	HD-FTP, SET

HD-FTP: Heavy Duty Federal Test Procedure
SET: Supplemental Emission Test
Values in parenthesis: g/kWh (conversion factor: 1 g/bhp-hr = 1.34 g/kWh)
Limit values for CO and HC not shown here

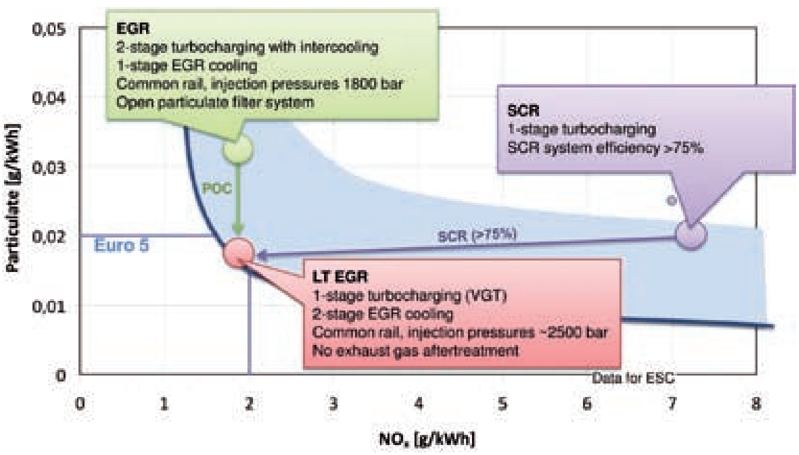


Figure 1: Technologies for Euro 5 – state of the art for the NO_x/PM trade-off

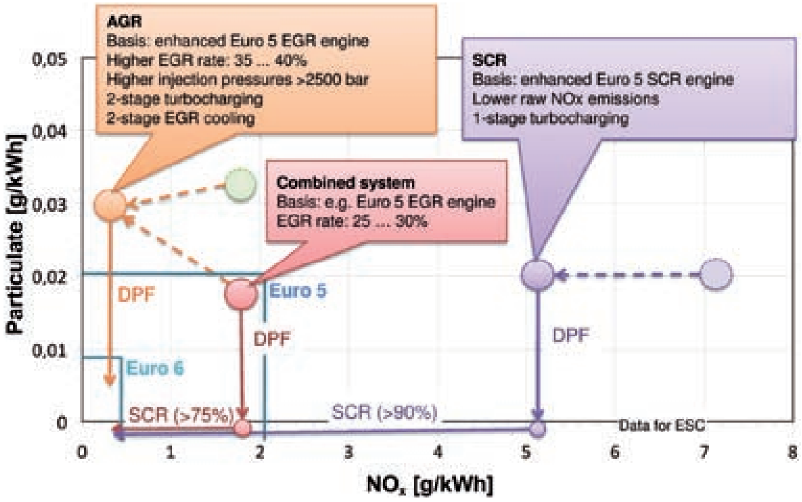


Figure 2: Technologies for Euro 6 – enhancements based on Euro 5

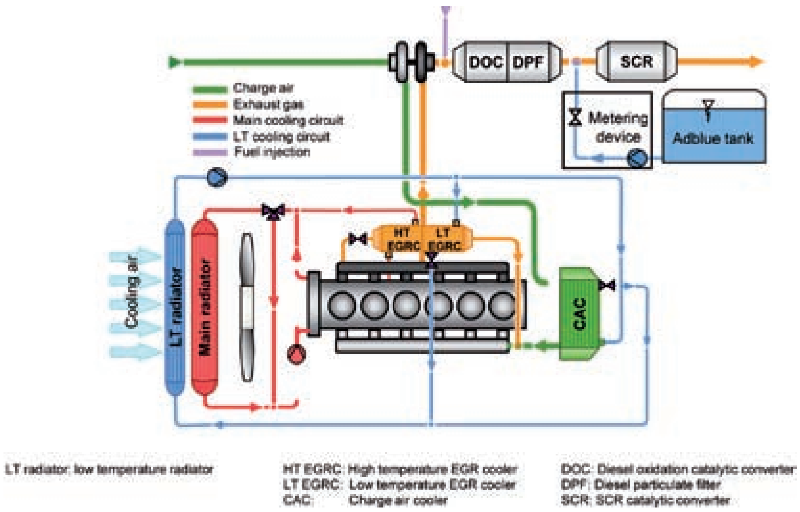


Figure 3: Combined system for Euro 6: EGR and SCR

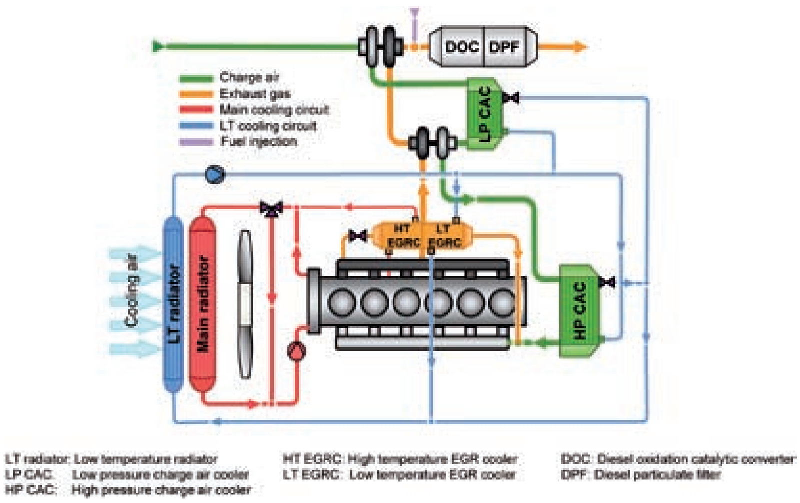


Figure 4: Potential two-stage EGR system for Euro 6

NO_x conversion rate is limited in two ways. In addition, the WHTC includes a cold test which further reduces the rate of conversion in the first part of the cycle. The resulting increase in NO_x emissions probably cannot be offset in the second hot parts of the test.

The transition from Euro 5 to Euro 6 requires an 80 % reduction in NO_x emissions. If this objective is to be achieved with selective catalytic reduction alone, the efficiency of the technology will have to be significantly increased, from around 75 % today to more than 90 %. That is not all: to offset the temperature effect from the new test cycles as described above it will be necessary to further boost the efficiency of the SCR system. Accordingly, it may be difficult to meet Euro 6 and US '10 using SCR alone.

One possible method for achieving the Euro 6 legislation would be to combine SCR and EGR technology, **Figure 3**. Since cooled EGR means less NO_x is produced in the engine, there is also less NO_x to be converted by catalytic reduction in the exhaust system. The drawback of this combined system, as mentioned previously, is its size and complexity.

4 Exhaust Gas Recirculation with Two Stage Cooling and Two Stage Turbocharging with Intercooling

4.1 Two Stage Exhaust Gas Cooling

Exhaust gas recirculation reduces the oxygen concentration of the cylinder charge, thus reducing the speed and temperature of combustion. Since the rate of NO_x formation is exponentially dependent on the combustion temperature, cooled exhaust gas recirculation is associated with a significant reduction in NO_x emissions. Cooling the exhaust gas also improves cylinder filling and reduces thermal stress on the engine components.

With cooled exhaust gas recirculation, some of the exhaust gas is diverted upstream from the turbocharger turbine and routed to the exhaust gas cooler via an EGR valve. In the case of two stage cooling, **Figure 4**, the first cooling stage is high temperature cooling (HT EGRC), the cooling medium is the coolant from the main cooling circuit, and in the second cooling stage (low temperature stage,

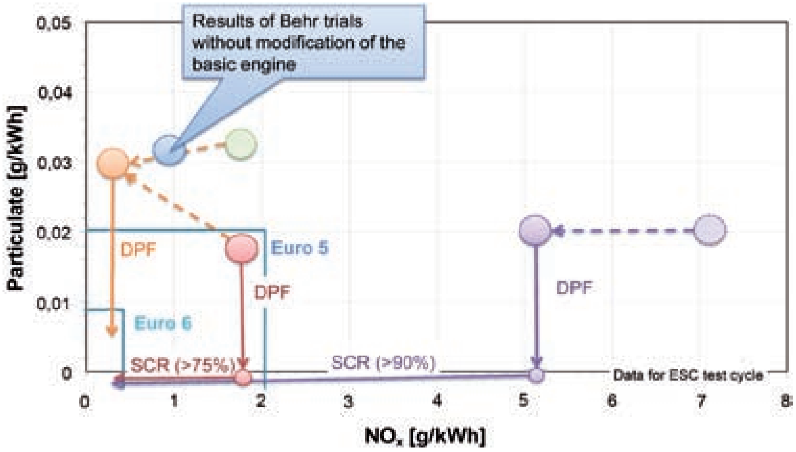


Figure 5: Potential of LT-EGR with respect to Euro 6

LT EGRC), it is the coolant from a low temperature circuit. To prevent the coolant from boiling in the first cooling stage, the exhaust gas and coolant flow in the same direction; the second stage operates in counterflow mode, which improves the cooling performance.

4.1.1 Self Cleaning of the EGR Cooler

A major advantage of two stage exhaust gas cooling – as compared with single stage cooling – is the self cleaning action of the EGR cooler and thus the stabilization of its cooling performance over the life of the cooler. This cleaning action is a consequence of the formation of condensation in the exhaust gas cooler. During the combustion, 1.26 kg of water for every 1 kg of diesel fuel is produced. Some of this steam condenses in the EGR cooler, where the condensation washes the deposits off the tubes of the cooler.

4.1.2 Cooling by Evaporation

Along with this self cleaning action, exhaust gas condensation also reduces the in-cylinder temperatures: firstly by the cooling effect from the evaporation of the charge air exhaust gas mixture and secondly by cooling due to evaporation of the intake air in the cylinder.

Cooling due to evaporation occurs when the condensate in the exhaust gas mixes with the dry charge air and evaporates. The heat required for this to happen comes from the charge air exhaust gas mixture, resulting in a fall in temperature of approximately 10 K. Because of the high dew point of steam, this cooling action occurs at high temperatures, for example 40 to 60 °C.

The exhaust gas condensate evaporates in the intake air but not completely: some water is remains and is conveyed with the intake air into the cylinders, where it evaporates in the compression phase. This second cooling effect limits the increase in the charge temperature during compression, lowering combustion temperatures and, therefore, NO_x emissions.

4.2 Two Stage Turbocharging with Intercooling

Cooling the charge air while keeping maximum cylinder pressures unchanged results in higher performance, lower fuel consumption and less formation of NO_x. In the LP and HP charge air coolers, Figure 4, the charge air, after being heated in each of the two compression stages, is cooled. The cooling of the charge air between the compressors, hence the term "intercooling", improves the efficiency of the second compressor.

4.3 Results

In various tests Behr together with AVL has already reduced NO_x values to about 0.8 g/kWh over the test cycle. However, the optimum has still not been reached. It might be possible to reach the Euro 6 limit, which is likely to be in the region of 0.7 to 0.4 g/kWh, **Figure 5**. It should, however, be noted that low temperature EGR is likely to be successful only in combination with two stage turbocharging and advanced fuel injection systems.

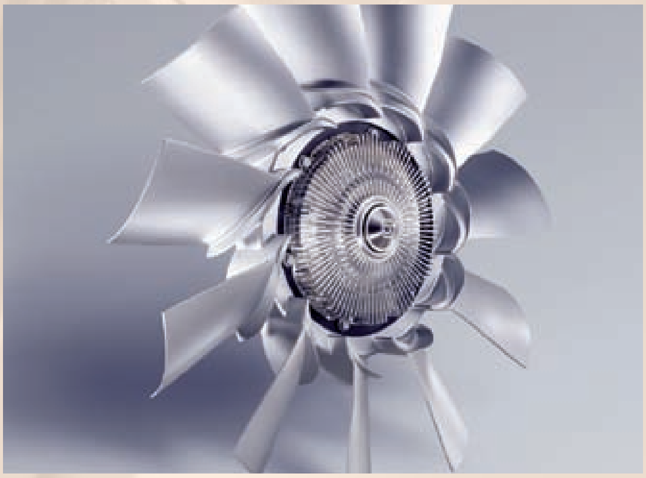
5 Conclusions

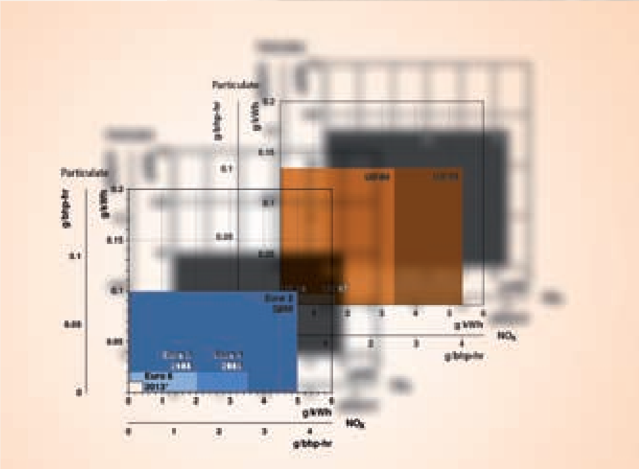
The Euro 6 and US '10 emissions limits are unlikely to be met using SCR technology alone. Cooled exhaust gas recirculation (EGR) will be part of the emissions solution. A combination of SCR and EGR is possible but may have weight, packaging, complexity and cost penalties.

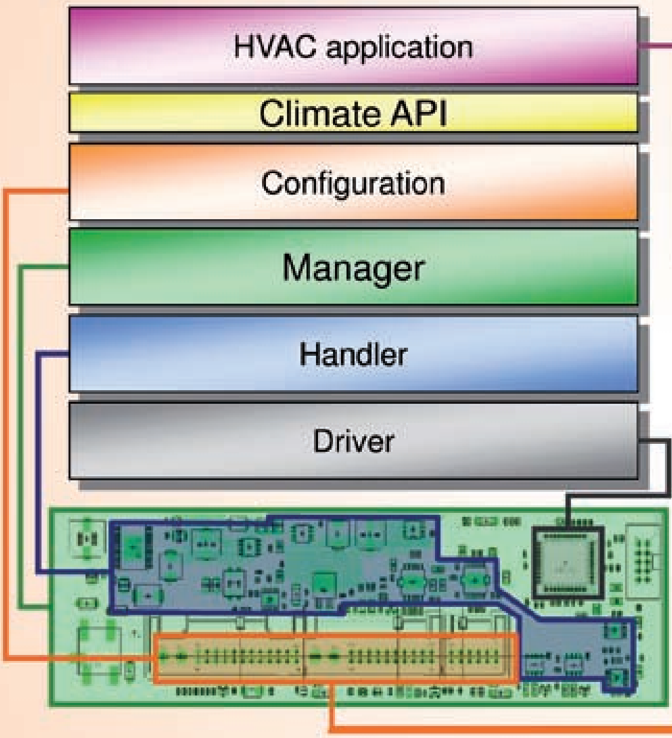
A possible solution is the two stage cooled exhaust gas recirculation process described above, combined with two stage turbocharging. This system possibly has the potential to achieve the potential Euro 6 limits. It should be noted that cooled EGR will also play a key role in enabling off-highway vehicles meet future emissions limits. ■

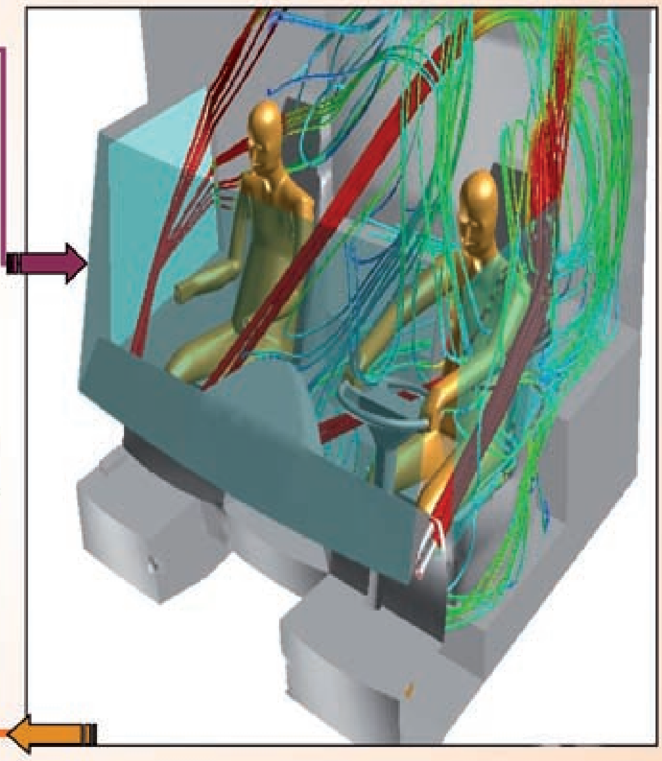
Special Behr

Thermal Management for Trucks









Ergonomics and Operating Concepts for Trucks

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort.

The Author

Ulrich Scheithauer is chief of product development Truckline/Thermomanagement at Behr-Hella Thermocontrol in Lippstadt (Germany).

1 Behr Hella Thermocontrol

Since the formation of BHTC as a 50/50 joint venture by the Behr and Hella groups in 1999, the company has grown rapidly and today is one of the world's leading manufacturers of control heads for HVAC systems. The product portfolio also includes control units (ECUs) for electric auxiliary heaters, blower controllers, and A/C sensors. The company counts the world's largest car and truck makers among its customers, and serves them not only from its parent plant in Lippstadt, but also from its subsidiary plants in North America, India, China, and, more recently, also in Japan. The BHTC mission is to provide "Comfort in Motion" by creating products that play a key role in ensuring optimum cimate comfort in cars and trucks.

2 Cars and Trucks: Differences in Climate Control

In recent years, there has been a sharp increase in comfort requirements for truck cabs. The driver's space is now recognized as a proper workplace. Ever more importance is accorded to the climate in the vehicle cab. Features that have long been standard in passenger cars have for some years now also been making their way into commercial vehicles. Today, no manufacturer can ignore its customers' demands for greater climate comfort. However, optimum climate comfort benefits not only the driver, but also all other road users as well: high interior air quality and a pleasant cab climate improve drivers' performance and help them to concentrate on the traffic.

Comfort is not only enjoying a pleasant climate in the driver's cab, but also the rapid response of the climate control system to changing climatic conditions. The system can thus ensure constantly mist-free windows and draft-free temperature control of the driver's workplace. The dash vents and the ventilation blowers are controlled in such a way that virtually no condensation forms on the windshield and side windows, and unwanted drafts are avoided.

Sensors measure the temperature at each of several points in the A/C system, and compensate for the influence of incoming solar radiation that falls directly onto the non-ventilated cabin temperature sensor. The climate control system can thus react quickly to changes.

Nevertheless, there are differences in the air conditioning of passenger cars and commercial vehicles that make the direct adoption of HVAC modules and control concepts from passenger cars impossible, **Figure 1**:

- A larger cab volume, and higher cabs.
- Commercial vehicles usually have a large, but vertical windshield. Compared with passenger cars, this results in less heat from solar radiation entering the cab in the middle of the day.
- Generally, the windows do not feature heat-absorbing glass comparable with that of passenger cars, and this results in a greater influx of heat when the sun is low.
- Cold outside temperatures, if they are not adequately compensated for by air conditioning, can result in an unpleasant flow of cold air at the windshield, leading to cold arms and thighs.
- Increased use as a result of ever denser traffic and frequent changes of drivers call for more user-friendly controls, that means it is important for the operator to quickly and intuitvely understand how the air conditioning system works.
- Owing to the greater movement range of the driver's seat, the operating controls must be larger and clearer in terms of their functional classification.
- The effect of the center air vent in the instrument panel is generally not so intense, owing to the greater distance to the driver.
- All system components must be designed for a longer service life.
- Today, some passenger cars have multi-zone climate control systems that must react more quickly to the changing amounts of incoming solar radiation due to the large sloping windows.
- Long-range trucks have a sleeper cab, which, in stationary operation, increasingly requires not only controllable heating, but also air conditioning; see the presentation on no-idle air conditioning.
- Passenger car platforms with high unit numbers of individual model series require specific climate control hardware and software components that are based on a standard module set. Control heads for truck air conditioning systems are also designed for platforms, but because the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software, **Figure 2**.

3 The New Climate Control System for the MAN TGX

For the design of the A/C control heads and ECUs for the air conditioning systems for the new MAN TGX, a modular concept was adopted from the outset. This concept makes a clear distinction between design and functionality.

The control head for the air conditioning system was thus integrated into the modern cockpit with significant space savings, and adapted to an individual design that meets demanding ergonomic and functional requirements. In all variants, mechanical Bowden cables from the control head to the HVAC system are dispensed with, and only six electric cables are used to connect the control head and ECU.

4 The HVAC Control Head

As the functionality of air conditioning systems increases, their operability often decreases. Especially in the case of commercial vehicles, owing to the long travel times with dense traffic, frequent changes of drivers, and the large movement range of the driver's seat, clearly identifiable and understandable controls are important.

We already provided an in-depth report on the link between operating ergo-

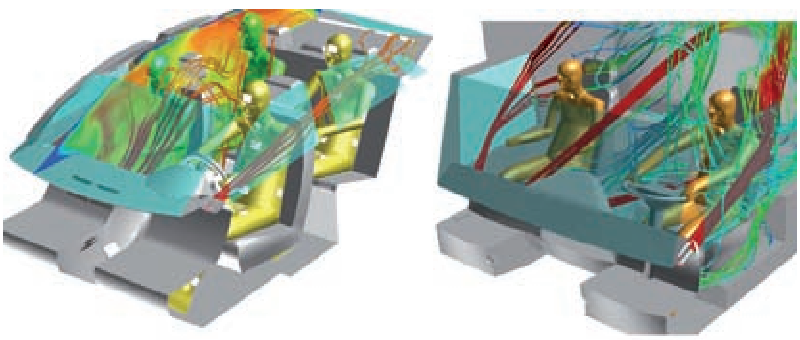


Figure 1: Cabin volume, layout and size of the windshield make up the big difference in the climate control between passenger cars and commercial vehicles

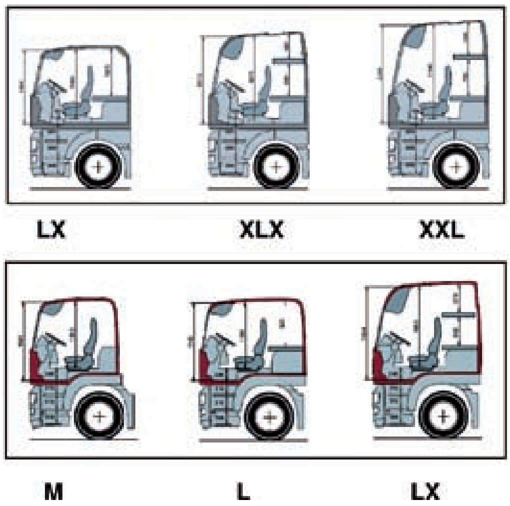


Figure 2: In commercial vehicles, the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software

nomics and traffic safety and a operability studiy carried out with the Technical University of Munich in 2007. Inadequate ergonomics lead to significant risks in traffic situations. The results show that easily recognizable symbols are based on:
- symbols/graphics
- depictions of people
- depictions of seats
- a vehicle contour to back up the symbols
- a combination of text and symbols.

Whereby symbols that are not easily recognized often contain text with no symbols, abstract symbols, or symbols that deviate from the international ISA standard.

The control heads for the MAN TGX therefore reflect the state of the art in relation to operating ergonomics, Figure 3.

In the fully automatic air conditioning unit, the driver selects both the desired air distribution and the blower speed by means of two control dials. The driver sets the temperature by means of two buttons, and the selected temperature is shown in a display. In the simpler heating variant, the temperature is set using the left-hand control dial, while the blower speed is changed by means of two buttons. In this A/C control head, particular importance was placed on easily understandable operation and ease of identification of the symbols for the switches and the display by both day and night. This is particularly important for trucks since they are driven for much longer periods, and also at night. It was therefore important to have highly contrasting images and clarity of symbols. This requirement was satisfied in all of the device variants by means of fail-safe LED lights, high-quality plastics technology for the operating buttons, and lasered symbols. In this way, with backlit symbols, no light can escape from the button control panel. Drivers receive an unambiguous acknowledgement from the system via the display in all control head variants, and can thus give their full attention to the traffic.

In the automatic mode of the fully automated system, the blower output temperature adjusts itself independently according to the vehicle's boundary conditions.

All the necessary settings for the air conditioning in the driver's cab and the sleeper cab in the new MAN TGX und TGS vehicles can be operated using a maximum of ten buttons and two control dials. One control head is therefore used to control both the driving and stationary operation. A second control head in the rear is therefore not necessary.

In order to ensure that the device has a long service life and is robust, and requires no maintenance, a non-ventilated interior temperature sensor (ITOS), Figure 4, was also used instead of the customary ventilated interior temperature sensor. The cab temperature is measured using the robust and maintenance-free sensor, and this is compensated for by means of a customized control system taking into account the incoming solar radiation, and also the heating of the device itself.

5 The Air Conditioning ECU

In the MAN TGX, a standardized air conditioning ECU was used for the first time. Behr and BHTC are thus responding to customers' demands for ever-smaller packaging dimensions of the control head and an individual design of the instrument panel with maximum control functionality.

For the climate control, a functional separation of the ECU and the A/C control head was selected, Figure 5. The heart of the ECU is a printed circuit board of modular construction and of standard dimensions. Thanks to the standard printed circuit board, the dimensions of

Figure 3: The control heads for the MAN TGX / TGL reflect the state of the art in relation to operating ergonomics

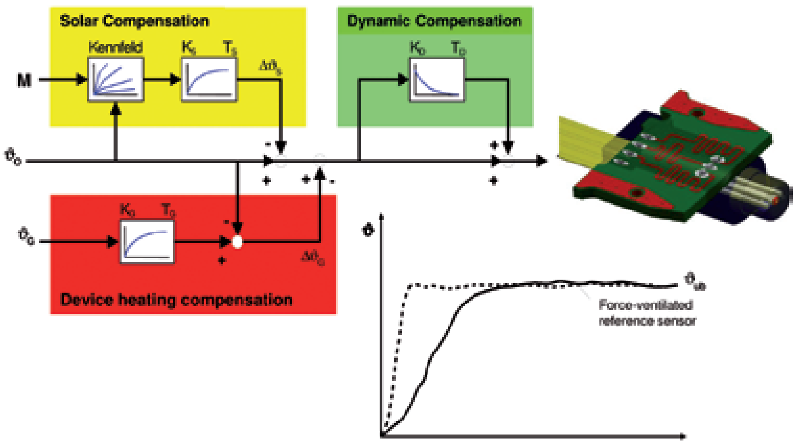


Figure 4: Compensation of heat up due to solar radiation and device heat up

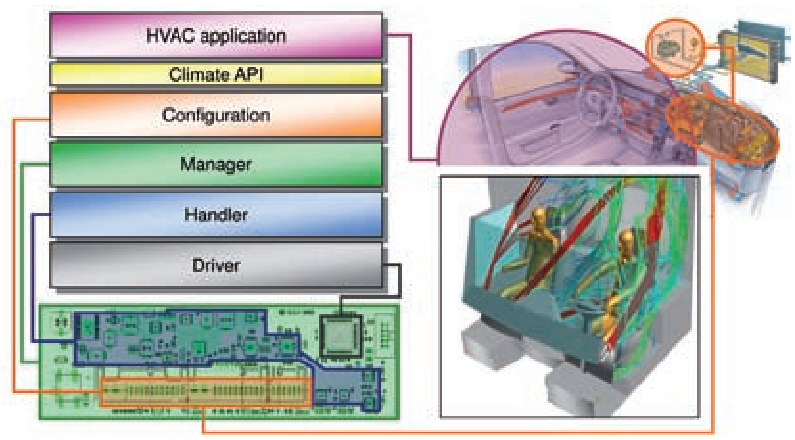


Figure 5: Architecture of the standardized air conditioning ECU – separation of function and design

the ECU and the connector plug are identical for all variants.

The ECU is installed in the vehicle in such a way that the HVAC module and ECU form a functional unit with short electrical connections. A mechanical coupling between the control head and the HVAC module is no longer required. In addition to the preferred mounting position on the HVAC module, other mounting locations in the vehicle are, in principle, also possible.

The open architecture and the less complex design of the control head give the customer more freedom in the design of the instrument panel in the vehicle than before, and better use is made of the existing space envelope. Other variants adapted to the customer's requirements can be obtained only by means of a different assembly and different programming of the processor. This reduces the development outlay required for variants, and cuts costs. The ECU is also flexible in terms of the interface to the customer's preferred data bus format.

6 Summary

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort. Operation of the air conditioning unit must respect ergonomic considerations, so that drivers take advantage of all of the capabilities of the A/C system on the one hand, and are not distracted from the traffic by its operation on the other.

With the unit's design and operating concept, BHTC has satisfied the increasing demands for an A/C control head that is modern, efficient, and at the same time user-friendly.

Whatever the initial climatic conditions at the start of the journey, or however they change during the trip, the climate control system always ensures consistently comfortable and draft-free air conditioning, and thus avoids any additional stress for the driver.

A climate control system that is functionally and ergonomically designed using state-of-the-art processes thus plays a key part in reducing the stress on drivers, and, thanks to the comfortable cab conditions, helps them stay relaxed in every traffic situation.

Non-idle Air Conditioning for Enhanced Road Safety and Reliability

Transportation of freight by truck is very important for the functioning of the economy and society. As the driving condition of the driver plays a key role in this, it is essential to provide adequate thermal and acoustic comfort during rest periods. A non-idle A/C system that provides air conditioning both during journeys as well as during rest periods and when the windows are closed, improves driver recuperation. The driver is thus better able to concentrate and feels fitter and more refreshed.

The Author

Dr. Lubens Simon is chief of commercial vehicle climate systems development at the Behr GmbH & Co. KG in Stuttgart-Feuerbach (Germany).

1 Introduction

Transportation of freight by truck plays a key role in the functioning of the economy and society in all Western countries. It is even more important that this transportation takes place in a safe, reliable, and eco-friendly manner, and that it is cost-efficient. Drivers play a key role in achieving this: their health, ability to perform and to concentrate, in short: their driving condition. In order to maintain this condition at a high level for the entire duration of the journey, drivers require a workplace that is ergonomically designed and has a pleasant cab climate.

This involves a high level of thermal and accoustic comfort, which is important not only during the journey itself, but also when any stops are made, whether they are voluntary or involuntary. The thermal comfort is particularly important in driver rest periods, because otherwise the degree of recuperation is reduced. This applies especially to the sleeping phase, since drivers who are not well-rested pose a danger to themselves and to other road users. The infamous "miscrosleep," one of the greatest causes of accidents, is primarily due to inadequate or unrestorative sleep. Non-idle air conditioning, that cools the cabin also during the rest periods with windows closed, enhances the thermal comfort of the driver and thus his ability to concentrate.

2 Driver Survey on the Use of Non-idle A/C Systems

In 2006, Behr surveyed 500 truck drivers from different countries with different vehicles at a total of six rest areas along Germany's main highways. The aim of the survey was to find out how the drivers use the cab as a living space, and what the requirements of this living space are (with a focus on air conditioning), and also what the future requirements of the market are, and which product strategy can be developed from this information.

After this general questioning, 16 drivers were selected for a longer interview. These people formed a representative market cross-section of long-distance drivers who had a non-idle A/C system.

It was found that the great majority of the drivers believe that a non-idle air conditioning unit is important. Around 90 % of the drivers who did not have this sort of system in their vehicle would choose to have one. Since only one fifth of all long-distance trucks are equipped with non-idle vehicle air conditioning, there is a very high market potential. By contrast: parking heating systems are found in all heavy-duty trucks. A summary of the driver's views: Non-idle air conditioning systems ...

- ... are used in a similar way as parking heaters, and are valued just as highly by drivers
- ... are nevertheless available commercially only at a market level of 20 %
- ... are perceived as improving drivers' personal safety
- ... avoid engine idling, and thus prevent fuel consumption and engine wear
- ... should provide air conditioning at night for up to ten hours, and for up to two hours during the day with incoming solar radiation
- ... should provide automatically controlled air conditioning for the entire cab
- ... should not require any servicing or any initial activation.

According to this information, non-idle air conditioning systems have a high market potential. From these and further results of the survey, the following specifications have been provided:

Non-idle air conditioning systems should ...

- ... cool the cab during overnight stops for up to ten hours and for up to two hours during the day (even with strong incoming solar radiation)
- ... provide draft-free cooling of the entire cab (not only the space above the bed)
- ... have automatic temperature control
- ... be reliable and easy to operate
- ... not require any maintenance; the charging of the energy storage devices (cooling battery or battery pack) should occur automatically
- ... be interfaceable with an automatic fresh air supply.

The requested hours of operation and performance can be fulfilled by electrical systems. Also, roof units will fulfill the expectations on non-idle a/c units. The non-idle air conditioning systems currently available on the market are still highly inadequate compared with what drivers want in terms of both their technology and their performance. In order to satisfy all of the requirements of the users, Behr has set itself the following additional design objectives for non-idle air conditioning systems:

- a low current draw in order to allow battery pack operation
- installation in existing roof openings for aftermarket applications
- satisfy truckmakers' installation requirements, specifically in terms of quality, durability and reliability and integration into the operating system architecture.

On the basis of these design objectives, an electric non-idle air conditioning unit

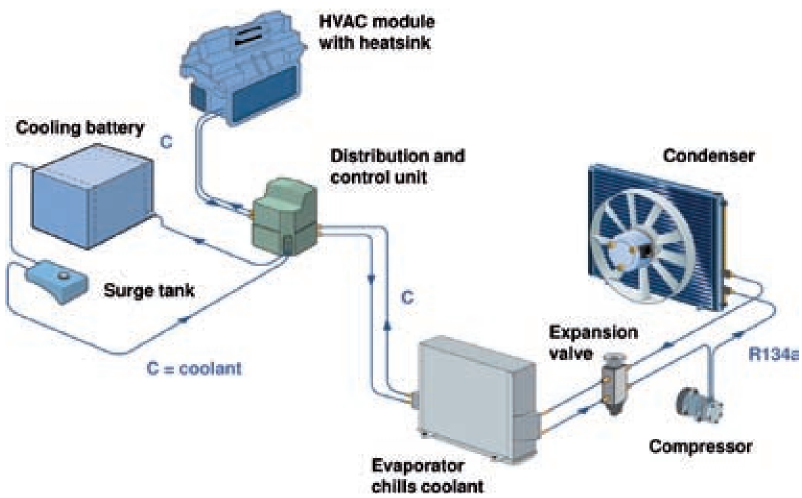


Figure 1: System diagram of the non-idle air conditioning with cooling battery from MAN

in the form of a roof unit was designed and constructed as a demonstration model, in addition to the non-idle air conditioning system with a cooling battery that is already in series production. Design of a rear wall unit is currently under way.

3 Technical Features of the Cooling Battery System

The non-idle air conditioning system with a cooling battery is fully integrated in the vehicle, and replaces the conventional engine-driven air conditioning system. The system has a secondary circuit **Figure 1**. In the charging phase, a conventionally operated refrigerant circuit intensely cools a liquid refrigerant in a special evaporator. This coolant, controlled by the distribution unit, cools both the heat sink in the HVAC module as well as the contents of the cooling battery, which therefore freezes. The heat sink replaces the conventional evaporator in the HVAC module; it cools the cab air during the journey, and during breaks in the journey. In the non-idle A/C system, the refrigerant circuit is in the resting state. By means of the circulating refrigerant, the heat from the vehicle cab is slowly transferred to the cooling battery, where the frozen content of the cooling battery is liquefied. The system with the cooling battery is fitted as standard in the heavy commercial MAN vehicles TGA (since 2003) and the more recent TGX from MAN (since 2007).

4 Technical Features of the Roof Air Conditioning Unit

This plug-in 24-V unit can either be factory fitted or retroffitted on the aftermarket. The unit is made up of an electrically operated, conventional refrigerant circuit that essentially consists of a compressor, condenser with fan, receiver, blower, and evaporator with expansion device, **Figure 2**. These components are housed in a single module that projects into the roof opening of the vehicle. Inside the cab, a screen allows drivers to see only the air inlet and the air outlet openings, and the control head. **Figure 3** shows a cross-section through the roof unit installed in the ceiling of the cab, and how it works.

The unit is operated with recirculated air. Control of the fresh air supply is integrated in the control system of the engine-driven air conditioning unit. For the power supply, in addition to the starter batteries, an additional battery pack, for example consisting of lead-gel batteries, must be provided in the vehicle. Some of today's systems are, in fact, powered by conventional starter batteries, but these are not really suitable for operating non-idle air conditioning systems because they are designed to deliver a high current over a short period of time. The non-idle air conditioning system must, however, be supplied with power over several hours. In a nine-hour operation, the battery is almost completely drained, and thus needs to be recharged. If a starter battery was frequently charged and drained, its capacity would quickly be reduced even after 15 such cycles to under 40 %. Starter batteries are therefore unsuitable for this application.

Lead-gel batteries, by contrast, are cycle-proof, that means they can be repeatedly recharged to a high capacity.

The roof air conditioning unit provides sufficient power to air-condition the cab, even with incoming solar radiation during the day. The two-hours-per-day period of operation determined from the driver survey is not, however, the critical value for the battery pack, but instead night operation of up to ten hours. In the case of an average power consumption of the unit of only 400 W, this would require, for example, a battery pack with four standard size traction batteries. The low power consumption of 400 W is the result of the system's exceptionally high efficiency.

Figure 4 uses measured values from the Behr climatic wind tunnel to show the course of air conditioning at night

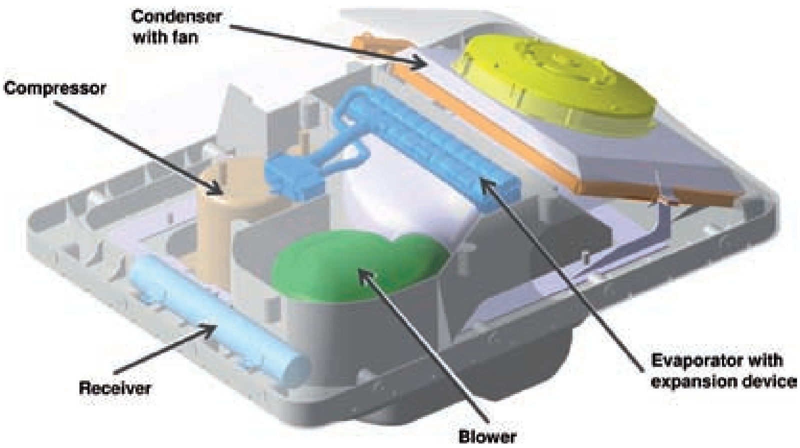


Figure 2: Schematic depiction of the electrial roof air conditioning unit

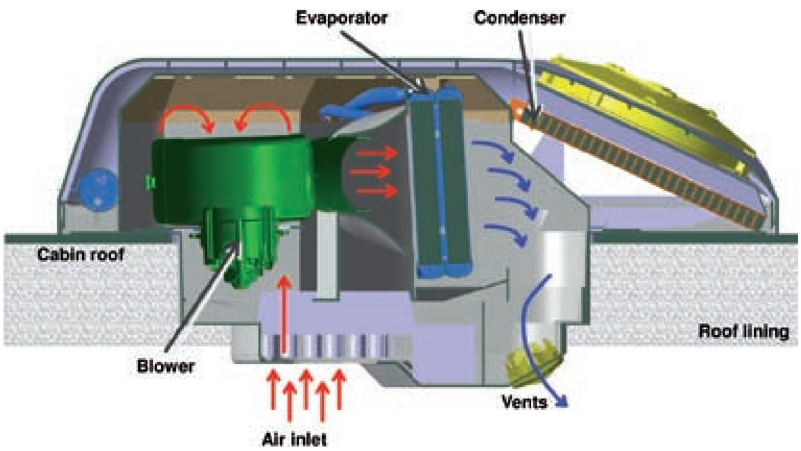


Figure 3: Side view of the electrial roof air conditioning unit

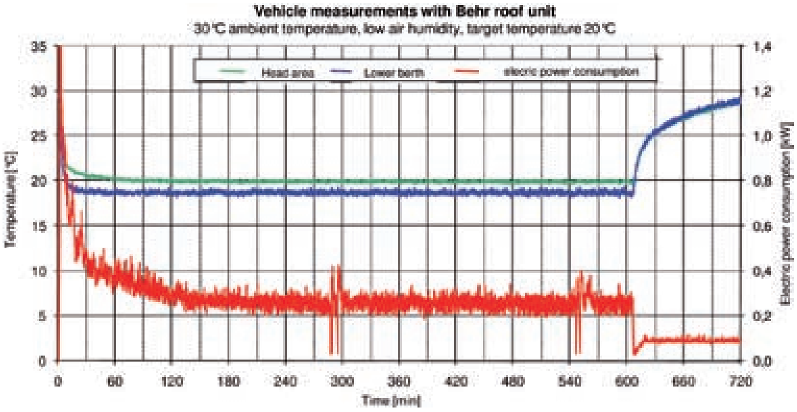


Figure 4: Cool down and power consumption of the electrial roof air conditioning unit at night

with an outside temperature of 30 °C. The target temperature of 20 °C is very quickly achieved and maintained, thanks to the temperature control over the ten hours. The power consumption is almost always less than 400 W.

5 Advantages of the Electrical System

The electrical system has two advantages over the system with the cooling battery: for one thing, drivers can access the cooling capacity at almost any time, because the batteries can store the power supplied by the generator for a long time. They therefore do not need to plan the charging or even to initiate it, since this happens automatically. During the journey, the battery pack is then constantly maintained in the fully charged state. In the system with the cooling battery, the charging of which is initiated manually, it is not possible to exclude the possibility that the driver may one day forget to initiate the charging, or may initiate it too late. If cooling is then required, there may be no or insufficient cooling capacity available. This point was also mentioned in the driver survey, which then also led to the call for an automatic charging of the cooling battery or battery pack.

The second advantage of the electrical system is that, with the battery pack for the non-idle air conditioning unit, additional electrical devices can also be operated, for example a television, computer, microwave oven, or coffee machine. Because the starter battery need not be used to do this, it therefore cannot be drained accidentally.

6 Behr's Development Capacity

As an original equipment manufacturer and systems supplier of passenger car and truck air conditioning units, Behr designs not only the HVAC modules, but also the control heads and associate software, working with joint venture companies such as Behr-Hella Thermocontrol (BHTC). This calls for expertise in the communication processes in the vehicle and for close collaboration with the vehicle manufacturers, for example for the construction of an interface between the engine-driven and non-idle air conditioning systems. Such an interface is required, for example, when the fresh air supply to the cab is to be taken over by the engine-powered A/C system instead of the non-idle air conditioning unit. This is particularly desirable when the truck's engine-driven A/C system is equipped with active carbon filters. In this case, the cab is supplied with filtered, gas-free air that increases drivers' safety when they are asleep. Generally, the fresh air is supplied at intervals, activated, for example, by a timer. The timed control saves battery power, but still guarantees an adequate supply of fresh air.

7 Summary

Non-idle air conditioning systems have considerable market potential, comparable with that of parking heaters, with which almost 100 % of long distance trucks are equipped. Behr's electrical units satisfy all relevant performance requirements, and have proven to provide a higher cooling capacity and higher efficiency than all comparable systems. A further advantage of the Behr units is their reliability, because the system components were designed specifically for use in trucks, and are sourced from series production of vehicle air conditioning units. ■

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US '10 envisages another drastic reduction in NO_x emissions for commercial vehicles.

Measures for Satisfying Future Exhaust Emissions Standards in Special-purpose Vehicles

1 Behr Industry

When Behr Industry was founded in 1990, the objective was to cater to special markets in the engine cooling and air conditioning sectors. The justification for this was that technical and legal requirements were made with respect to the components and systems of off-highway vehicles that were completely different from those for the passenger car and commercial vehicle markets – requirements that cannot be satisfied by simple modification of an existing component or of an existing system.

The split of Behr Industry and Behr GmbH & Co. KG essentially reflects our customer structure, since Behr's customers often operate in different market segments, and under different names. Today, Behr Industry is active in the markets for buses, heavy-duty engines, railway vehicles, aircraft, construction and agricultural vehicles, electronics, military products, and gensets (that means diesel-engine driven generators for generating electricity). The most important requirements are:

- The smaller production volumes or even single unit productions, also mean, that different development procedures, manufacturing technologies, and logistic concepts are necessary.
- The Euromot, EEV, and Tier X legislation governing emissions and CO_2

emissions is very similar to the Euro 5/6 and US ‘XX standards from the car and truck vehicle sectors – only time-displaced by about three years.
- Other constraints on cooling requirements, installed position, and the available installation space.
- In the special-purpose vehicles, the components and systems are exposed to different stresses: fouling through mud, dust, and fibers results in different focuses for the development of heat exchangers. In some shipbuilding applications, cooling takes place using the seawater itself. The corrosive action of the saltwater is countered with special stainless steel.

2 Small-scale Series Production

For example for buses, small-scale series production specifically means annual volumes of approximately 500 to 3000 units. In the case of railway vehicles, the figure can be as low as just five to 100 units per year. Behr Industry must therefore use other processes for manufacturing radiators and coolers and for assembling complete cooling systems. Semi- or fully automatic production equipment can be used only rarely, and the costs of die-casting or functional plastic components often cannot be redeemed, owing to the high capital costs involved. Flexible systems are called for that require little or no capital expenditure; however, these demand higher manual production outlay and highly skilled manufacturing staff. Behr Industry also endeavors to carry over products or components from high-volume series production and integrate them (for example buses and tractors) in order to take advantage of the cost benefits of large-scale series production. This significantly reduces R&D expenditure, validation requirements, and the risk of failures in the field.

Behr Industry also employs the general Behr production standards and development tools and tests and develops its products in the test facility of the parent company, and uses the same simulation tools (FE analyses, CFD calculations, BISS). This makes the development of new products specifically catering to special market requirements efficient and competitive.

3 Exhaust Emissions Standards

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US 10 envisages another drastic reduction in NO_x emissions for commercial vehicles. The corresponding standard for the off-highway sector is Euromot stage IIIB / Tier IV A, and will come into effect approximately three years after Euro 5 / US 10. The limits for NO_x and particulate emissions are not much different from those of commercial vehicles: Euromot stage IIIB envisages a reduction of nitrogen oxide emissions to 2 g/kWh, and of particulate emissions to 0.025 g/kWh (Euro 5 specifies 2.0 NO_x and 0.2 PM).

The exhaust emissions standards for off-highway vehicles in the USA are similar. The standards that are similar to the US07 and US10 standards are the Tier 4a and Tier 4b standards, which will come into effect at the same time as Euromot stage IIIB, that means three years later.

In the bus market, we find a special situation; here, the EEV (Enhanced Environmental Friendly Vehicle) preliminary standard was introduced. EEV is not a mandatory limit, but rather a voluntary standard that is virtually no different from Euro 5 in terms of the limits on NO_x and particulate emissions. EEV engines essentially already satisfy the Euro 5 standard that will be in force from 2009. The environmental awareness of the bus operators, in particular in large cities, leads to their voluntarily complying with special limits as per EEV.

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In order to comply with the exhaust emissions regulations and to save fuel in off-highway applications, as in the case of commercial vehicles, systems such as cooled exhaust gas recirculation or two-stage turbocharging are used, **Figure 1**. Here, too, this similarly leads to increasingly complex cooling systems every time the exhaust emissions laws are tightened further. Higher charge air temperatures and pressures and quantities of heat in the coolant call for new solutions for heat exchanger design. The integration of cooled exhaust gas cooling and indirectly cooled charge air requires considerable systems expertise in order to be able to guarantee the necessary cooling within the special constraints of the off-highway market.

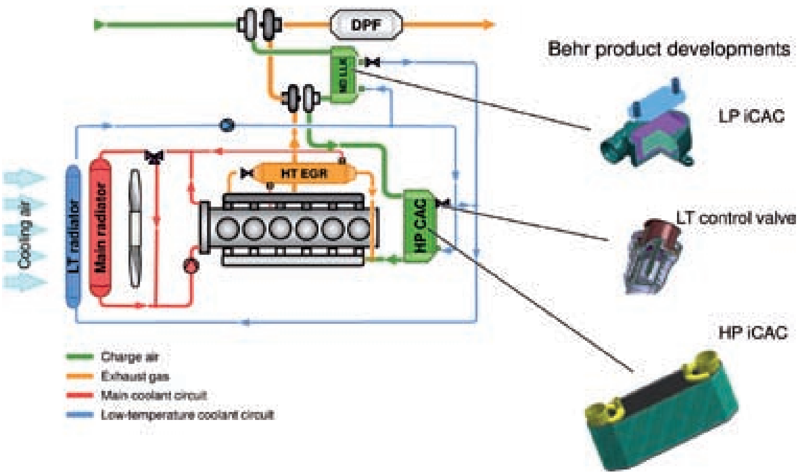

Figure 1: Schematic representation of a two stage turbocharging with indirekt charge air cooling

4 Fouling

A distinctive feature of special-purpose vehicles is their use in very different areas of application: mines, fields, rails, water, construction sites, forests, or garbage dumps. Fouling on the external surface through which cooling air passes thus takes very different forms. Sand, dust, oils, pollen, leaves, plant debris, grass, litter, and many other soiling agents in every possible combination accumulate on the air side inside the radiator and between the fins, Figure 2. This leads to a higher air-side pressure loss and restricts the flow of cooling air. The radiator can no longer provide the desired cooling power to the engine, and engine performance decreases accordingly.

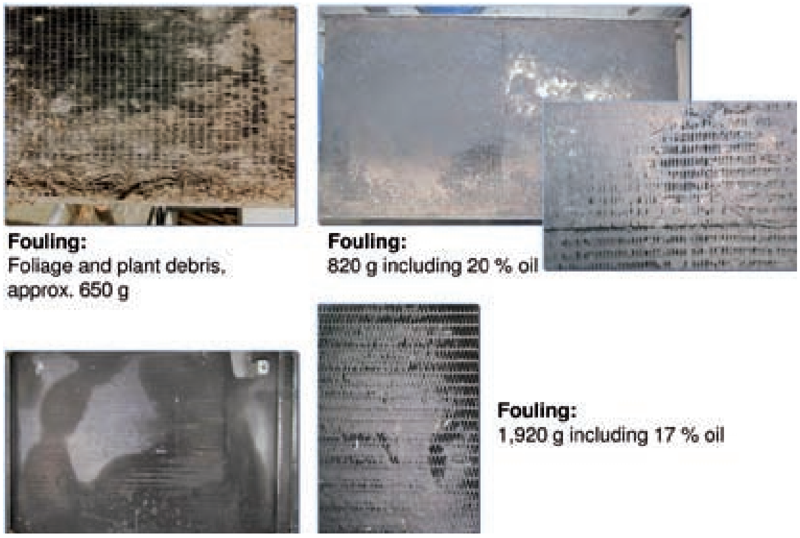

Figure 2: Representative examples of different foulings as found in off-highway applications

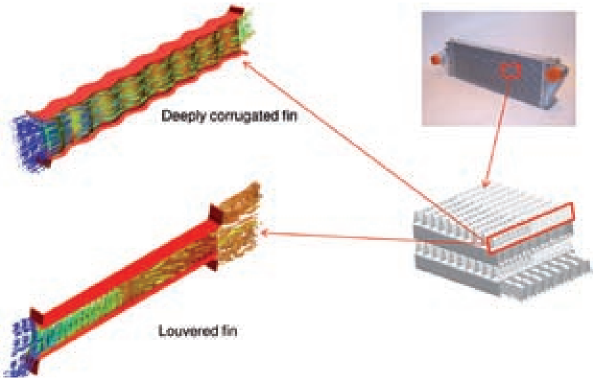

Figure 3: Comparison of a deeply corrugated fin and a louvered fin

Here, conventional radiators with louvered corrugated fins cannot be used. Behr Industry has developed special cooling air fins specifically for these applications. Unlike conventional fins, these do not have any louvered structure on their surface; instead, they are flat or corrugated. In car or truck radiators, these louvers serve to improve heat transfer between the cooling air and the cooling water, because the air does not pass through the fins in a laminar flow, but instead turbulence is produced on the louvers, Figure 3. However, a lot of dirt particles collect on these louvers that cannot be removed by using compressed air, for example. If there are no louvers, dirt particles can be blown away against the direction of flow.

In order to understand the mechanisms of fouling and to draw the appropriate technical conclusions, Behr Industry has been working closely with a number of institutes for several years. Figure 4 and Figure 5 show the results of tests on different cooling air fins that were realized in collaboration with the ILK Dresden (Institute of Air Handling and Refrigeration Technology in Dresden). These tests investigated to what extent the pressure drop on the cooling air side is dependent on the dust concentration and the fin used. It was found that the flat fin has the smallest pressure drop. Figure 5 shows the results of similar tests, but under more realistic conditions using fibers as the fouling agent. A flat fin, a staggered fin and a louvered fin were exposed to fibers during usage and the cooling air side pressure drop was measured over time. After a predetermined cycle had been completed, the fins were cleaned with compressed air. It is observed that the pressure drop in the louvered fin is worse after every cleaning cycle compared with the flat fin and the fin with deep corrugations. This is because fibers penetrate deep inside the fins, and, in the louvered fin in particular, can then no longer be removed. Therefore, over time, the radiator with the louvered fins becomes clogged up, and can no longer be cleaned.

Of course, the efficiency of the radiator decreases with the soiling of the louvers. Together with our customers, we must therefore arrive at a compromise between the prevention of fouling and the performance density of the radiator.

Furthermore, the arrangement of the individual coolers (radiator, charge air cooler, etc.) can play a role in minimizing the susceptibility of the cooling module to fouling. In conventional radiators, the individual radiators are arranged one behind the other ("face to face"). The problem here is that dirt particles may pass through the first radiator and become caught in the second one. For cleaning, the cooling module would have to be dismantled. To avoid this, the radiators can be arranged next to one another ("side by side"), so that all of the faces can be cleaned from the outside. Alternatively, the frame of the cooling module can also be designed to swing open, in order to facilitate cleansing of the second radiator, Figure 6.

5 Systems Expertise

All of these requirements must be implemented for a small market that individually caters to specific customers. Behr Industry provides not just the coolers and

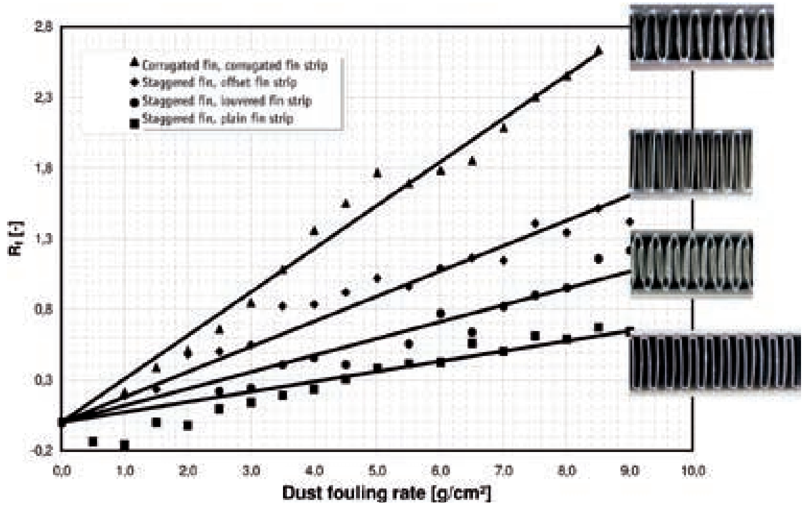

Figure 4: Fouling: Impact of dust on the pressure loss in coolers. Investigations performed by ILK Dresden on behalf of Behr Industry

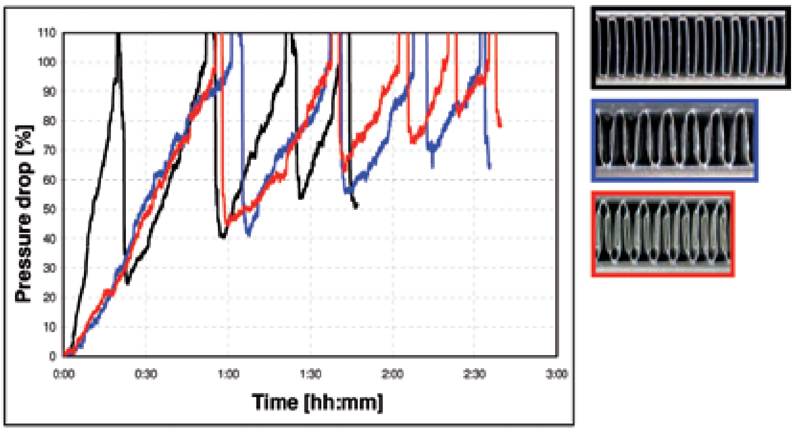

Figure 5: Fouling: Impact of fibers on the pressure loss in coolers and the regeneration of coolers with different fins. Investigations performed by ILK Dresden on behalf of Behr Industry

Figure 6: Solutions designed to prevent fouling – cooling module for city bus featuring swing-out device (top); tractor cooling module with coolers arranged in parallel on the cooling air side (bottom)

radiators themselves, but also complete ready-to-install cooling systems including the radiator/coolers, fan, fan drive, frame, and, if required, also the surge tank, water and oil pumps, and level controller, working in close collaboration with and for its customers.

When solving these technological problems, Behr Industry calls on Behr‘s development methods, results and products, as they are described in the article “Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles”. Behr Industry uses this technology and adapts it to suit the respective engines and the needs of the different special markets. Indirect charge air cooling is standard in commercial vehicle engines. The corresponding indirect charge air coolers are designed in a stacked plate construction. Behr Industry adapts the coolers for a potentially higher engine power. This can be achieved with a simple scaling, that means an increase in the quantity of stacked plates, for example, or, alternatively, by means of bundling existing EGR coolers when there are very high quantities of exhaust gas in the cooled exhaust gas recirculation, for example.

Because the installation position of the engines in special-purpose vehicles is often different from that of conventional commercial vehicles, adapting the components for the new installation position represents another challenge.

If the installation position changes, very often the air ducting on the cooling module or the position of the surge tank relative to the radiator changes as well. In conventional applications, the cooling air is routed from the front through the radiator into the engine compartment. In railway vehicle applications, for example, this is often not possible, owing to the installation position. In roof units, the air is conveyed laterally through the radiator and leaves the module at the top. In other locomotive applications, the radiators are located at the bottom of the module and the cooling air is routed through the assembly from the top to the bottom. If the surge tank for the cooling medium cannot be mounted above the radiator, technical solutions such as an anti-cavitation tank or two-chamber system must be found in order to ensure that the cooling circuit remains free of air. ■

In recent years Behr has made such progress in developing cooled exhaust gas recirculation and iCAC systems that commercial vehicle manufacturers now have at their disposal reliable, production-ready solutions for reducing NO_x emissions. When used in combination, these new cooling systems can meet Euro 5 emissions requirements without the need for a special exhaust treatment process such as selective catalytic reduction (SCR).

Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles

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1 Introduction

And in contrast to SCR, these innovations do not require any additional operating agent. When they are used in conjunction with the latest engine and injection technology there is no increase in fuel consumption, and they also allow weight reductions at comparable costs. Further benefits are the flexibility of application of these new solutions, and their high potential for further development to meet Euro 6 requirements.

2 Emissions Standards and Reduction Technologies

2.1 Emissions Standards

Since 1992 (Euro 1), the limits for heavy trucks have been brought down in five stages, including some very drastic reductions. Since 2000 (Euro 3) emission limits for NO_x have been reduced from 5 to 2 g/kWh, and particulate emissions from 0.10 to 0.02 g/kWh. In percentage terms this corresponds to a 60 % reduction for NO_x and 80 % for particulates.

2.2 Exhaust Air Cooling and Charging

The exhaust gas recirculation process is essentially based on the fact that the exhaust gas has a higher heat capacity and a lower oxygen content than air. This causes the combustion temperatures in the cylinder to fall. The cooling of the exhaust gas and the charge air makes the temperatures drop even further. Because NO_x formation is an exponential function of these temperatures, a combination of cooled exhaust gas recirculation and turbocharging with CAC was able to meet the Euro 4 limits. Compliance with the stricter requirements of Euro 5 requires either an increase in EGR rates or a reduction in exhaust gas and charge air temperatures. The single stage EGR with two stage turbocharging plus intercooling, and two stage cooled EGR with single stage turbocharging are available for this purpose.

3 Engine Cooling Systems for Euro 5

Over the last few years Behr has been investigating how the increasingly stringent limits can be met by improving engine cooling. In particular, efficient charge air and exhaust gas cooling have a positive effect both on NO_x formation in the combustion chamber and fuel consumption. The newly developed production-ready engine cooling systems for Euro 5 and their components are described below, including comparisons with the SCR system.

3.1 Engine Cooling System with Single Stage Exhaust Gas Cooling and Two Stage Turbocharging

Figure 1 is a functional schematic of such a cooling system. It comprises an exhaust gas cooler which is cooled by the engine coolant, and a low temperature (LT) cooling circuit which contains two charge air coolers and a low-temperature radiator. Since the LT-radiator has a large frontal area and is the first cooler to be exposed to the cooling air flow, very low charge air temperatures can be obtained. This type of CAC is called indirect CAC.

In the EGR cooler, **Figure 2**, the exhaust flow component for recirculation, removed from the engine at the exhaust manifold, is cooled and then added to the charge air upstream of the intake manifold. This causes the temperature of all the intake air to be lowered, which reduces the production of NO_x. However, single stage EGR cooling as used for Euro 4 is not sufficient for Euro 5; this requires either more intensive cooling or an increased EGR rate. For the latter, in order to provide a sufficient oxygen concentration in the cylinder, it is necessary to have a higher charge pressure, which in this system is obtained using two stage turbocharging with intercooling. Two stage turbocharging enables a constant engine output to be maintained in spite of increased EGR rates, and prevents any increase in particulate emissions.

In both charge air coolers the charge air, which undergoes intense heating in each of the two compression stages, is cooled back down and some of the heat which was absorbed is transferred to the liquid coolant. In the LT-radiator this heat is then dissipated into the ambient air. This radiator is installed in the vehicle frontend, which in today's truck diesel engines is the normal location for the conventional charge air cooler, connected to the turbocharger and to the intake manifold of the engine via bulky air ducts. These ducts can be eliminated with indirect CAC, which saves space and simplifies packaging.

The indirect charge air cooler can have a very compact design thanks to its high level of efficiency (compared to a charge air-to-air cooler), and this makes it possible to place the cooler between the turbocharger and the intake manifold. This also means that the charge air ducts do not need to be diverted. The charge air pressure loss can thus be reduced by up to 50 % and the charging pressure can be increased accordingly, which both improves cylinder air filling and simplifies the gas exchange process. Both factors reduce the fuel consumption at a given output.

Dispensing with the air ducts also reduces the air volume in the system. In a 12-l diesel engine a reduction of the air volume of more than 50 % was achieved thanks to iCAC. As a result the system reacts more quickly to load changes. Unlike the situation in passenger cars, however, in commercial vehicles it is not a matter of rapidly increasing torque, but of preventing emissions, for example particulate emissions. The well-known cloud which a truck without a particulate filter produces when the driver suddenly accelerates, happens because the turbocharger cannot supply the amount of air required for full-load operation straight away. There is then not enough oxygen for full combustion of the fuel, and particulate formation briefly increases rapidly. The smaller air volume thus reduces particulate emissions into the environment or the charge build-up on the particulate filter.

The intercooling of the charge air has a positive effect on the efficiency of the second charger. The charging pressure, which today involves pressures of up to 3.6 bar in the case of single stage turbocharging, can reach values of 4 to 5 bar absolute with two stage turbocharging and intercooling. As already described,

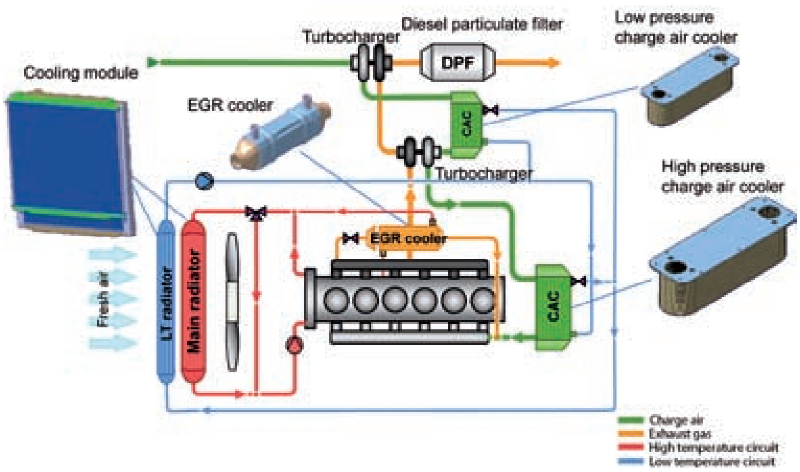


Figure 1: Engine cooling system with single stage EGR cooling and two stage turbocharging

this makes it possible to increase the EGR rates without reducing performance or increasing particulate emissions. Furthermore, a higher charging pressure theoretically opens up the following optimization opportunities:

- Increase in the power density (power per unit of displacement) of the engine. This leads either to increased engine output for the same displacement or smaller displacement for the same engine output ("downsizing"). The latter in particular has a positive effect on fuel consumption due to reduced friction in the engine.
- Increase in the excess air in the cylinder. Owing to the higher oxygen concentration in the cylinder this has a positive effect on soot formation. In other words the fuel is almost completely burned up, and less particulate matter is produced.

3.2 Engine Cooling System with Two Stage Exhaust Gas Cooling and Single Stage Turbocharging

In this system, **Figure 3**, the exhaust gas to be recirculated is first fed to an exhaust gas cooler which is cooled by the engine coolant. It is then routed to a second cooler which, as shown in the functional diagram, is located next to the charge air cooler. In this cooler the exhaust air is cooled by the ambient air. The air flow required for this is produced by the fan and/or by the airflow past the vehicle, according to the travelling speed.

Since the exhaust air is cooled in two stages in this system, resulting in lower exhaust gas temperatures, single stage turbocharging with CAC is sufficient to meet Euro 5 requirements. The charge air is cooled by the ambient air as in a conventional charge air cooler. This is why it is installed at the front of the vehicle where the ambient air flows through it. In this cooling system the exhaust gas and charge air can be brought to approximately the same temperature levels, which significantly lowers the mixing temperature upstream of the Intake manifold. In contrast to the shown separate arrangement of the charge air cooler and exhaust air cooler, this is an integrated cooler, that means a single unit comprising the charge air cooler and the exhaust air cooler.

4 Product Innovations

4.1 Integrated Exhaust Gas Cooler and Charge Air Cooler

The system consists of series-connected individual exhaust gas coolers, **Figure 4**, operating with different cooling media: engine coolant and ambient air. The air-cooled EGR cooler is integrated into the charge air cooler. This form of integration is the first of its kind worldwide.

The exhaust air cooling process: the exhaust gas flows from the cylinders are brought together in the exhaust manifold. From there some of the exhaust flows into the exhaust gas (top right, Figure 4). In this first stage of exhaust gas cooling the exhaust gas is cooled by the engine coolant. This part of the exhaust flow is then conveyed to the second stage, the air-cooled EGR cooler, integrated into the top area of the charge air cooler. When ambient air temperatures are low, the air-cooled exhaust gas cooler can be circumvented by means of a bypass in order to prevent the cooler from freezing. In both cases the exhaust gas then enters the intake manifold and the individual cylinders. It has first been mixed with the charge air cooled in the charge air cooler, so that the intake air has a uniform composition and temperature, which is important for ensuring the same combustion process in all cylinders.

In the first stage of exhaust gas cooling the exhaust gas temperature is reduced to 200 to 150 °C. In the second stage, the low temperature stage, it is then reduced to 25 to 20 K above the ambient air temperature. This lowers the temperature of the intake air overall, based on the mix ratio of charge air and exhaust gas.

The core of the air-cooled EGR cooler consists of tubes conveying exhaust gas and corrugated fins lying between them. In this cooler too, the tubes have been stamped inside to form turbulence-generating winglets.

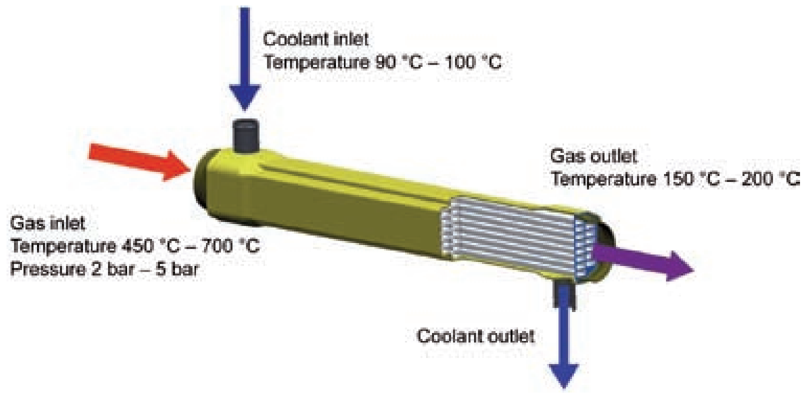


Figure 2: EGR cooler

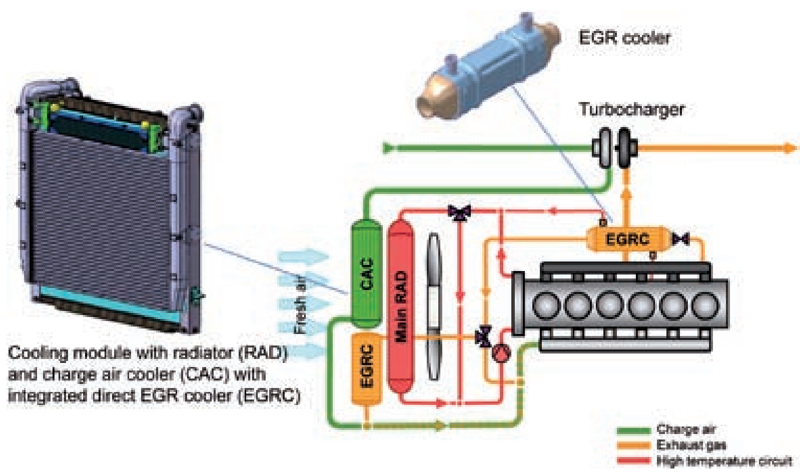


Figure 3: Engine cooling system with two stage EGR cooling and single stage turbocharging

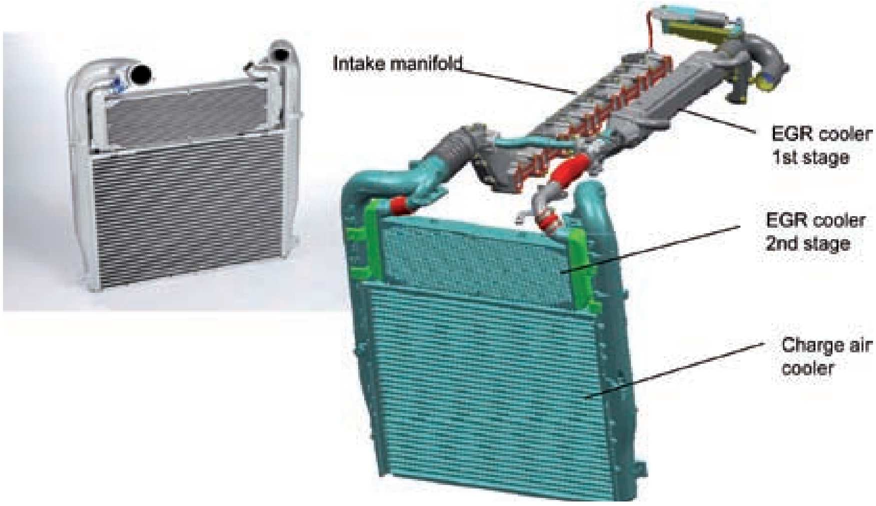


Figure 4: Two-stage EGR cooling: 1st stage coolant cooling, 2nd stage air cooling. EGR cooler integrated in charge air cooler

Figure 5: NFX 750 fan with ERS 250 fan drive

The tubes and corrugated fins are bonded together in a brazing process whereas the pipes and exhaust gas tanks are welded. The cooler consists of corrosion-resistant stainless steel tubes and corrugated fins and the exhaust gas tanks are also made of stainless steel. Features of the integrated charge air/exhaust air cooler module:

- optimized loss of pressure in exhaust gas and charge air cooler
- good mixing of charge air and exhaust gas at the mixing point
- bypass prevents freezing of the exhaust gas cooler
- no return flow of condensate into the charge air cooler
- EGR cooler is corrosion resistant.

4.2 iCAC with Integrated Thermostat

The higher EGR rates for Euro 5 compared to Euro 4 also necessitate higher charging pressures, leading to an increase in the charge air temperature. The charge air coolers used must therefore be able to withstand temperatures of more than 220 °C and pressures up to 5.1 bar absolute. Changes to the design of the charge air cooler can reduce the level of stress, which is based on the pressure and temperature load, to such an extent that the coolers are able to withstand the higher loads.

This aspect was taken into account from the outset for development work on the indirect charge air coolers and, as in the case of the charge air/EGR cooler module, development results were checked with stress analyses using the finite element method (FEM). The indirect charge air cooler is a stacked plate system comprising plates for the charge air and the cooling water ducts. Between the plates there are turbulators for the charge air and the coolant, which are optimized for heat transfer and temperature and pressure requirements.

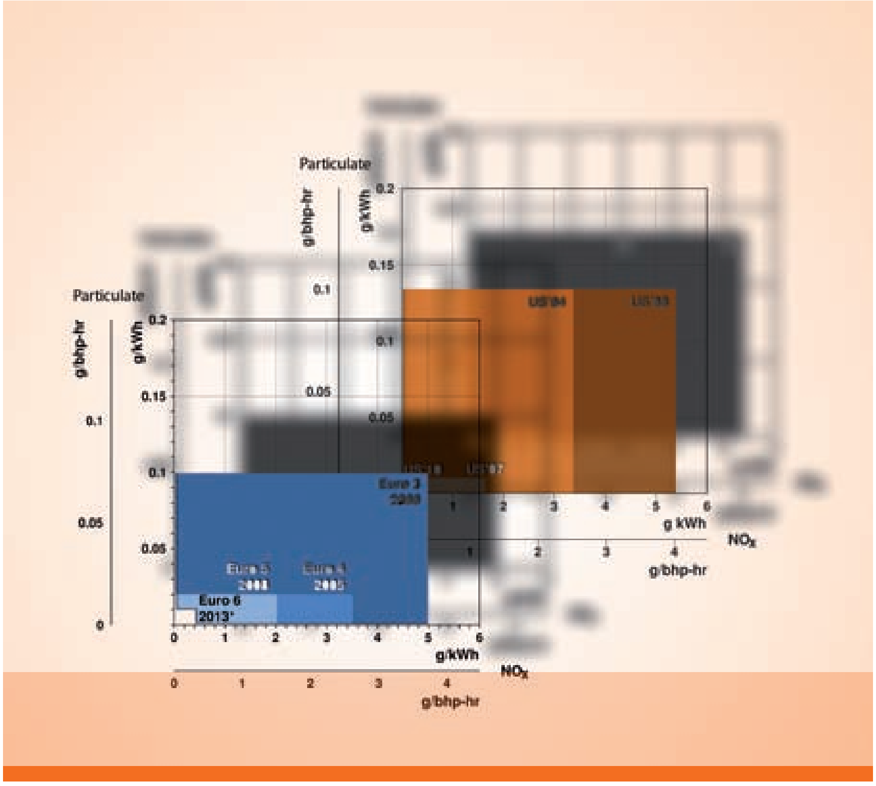
The charge air cooler is operated in a counterflow arrangement, that means the hot charge air flows in on one side and is cooled with cooling water flowing in the opposite direction. It was decided to use two intake ducts for coolant distribution. The coolant flow rate is controlled by means of temperature-controlled choke thermostats at the coolant outlet of the charge air cooler. According to the heat input from the hot charge air, the coolant flow rate is very quickly adjusted by means of fast-responding wax elements, thus avoiding the need for a complex control system.

4.3 Fan and Fan Drive

Fan output has been improved with the new NFX 750 fan, **Figure 5**. The modified blade geometry and higher number of blades (increased from eight to eleven) has boosted fan output while retaining almost the same axial construction depth as in the current series-produced model. The higher fan efficiency has also allowed the drive power to be reduced by approximately 10 % for the same mass air flow. The fan is driven by the Visco ERS 250 fan clutch. This electronically controllable clutch can transfer 40 % more torque than currently used fan drives with comparable size, along with significant improvements in controllability and dynamic clutch response. This means even more precise fan activation than before in response to the actual cooling demand, allowing the complete elimination of superfluous fan noise.

In order to cool the Visco fan drive sufficiently to accommodate its high operating range, the fan hub design has been optimally adapted to the clutch. Flow dividers and flow stabilizers in the region of the fan hub ensure that the inflowing cool air is conveyed through the cooling fins of the clutch and can then flow unobstructed through the fan blades. The result is improved cooling of the silicone fluid in the clutch and a higher slip power tolerance. Another effective means of protecting the silicone fluid in the clutch from overheating is continuous simulation of the silicone fluid temperature in the engine control unit. ■

The NO_x and particulate matter emission limits at Euro 5 and US 2007 (abbreviated as US ’07) for commercial vehicle engines are a major challenge for engine and exhaust gas aftertreatment technology. US ’07 is already in effect; Euro 5 will come into force in October 2008. Even more demanding technological challenges are to come: from January 2010, US 2010 (US ’10) limits will apply in the USA, and the introduction of Euro 6 is expected in 2013. However, the commercial vehicle engines, which will have to meet those limits are being designed now. Behr’s low temperature exhaust gas recirculation provides an appropriate technology for these engines.



NO_x Reduction Potential of Cooled Exhaust Gas Recirculation in Euro 6 Commercial Vehicles

The Author

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1 NO_x and Particulate Limits

The **Table** (top) shows how far the limits have reduced from Euro 3. The Euro 6 values are still to be finalized but will involve drastic reductions: in the case of nitrogen oxides (NO_x) probably by more than 80 % (from 2.0 to 0.4 to 0.7 g/kWh) and for particulate matters (PM) by more than 50 % (from 0.02 to less than 0.01 g/kWh). In the USA the forthcoming US ’10 limits for NO_x are 0.20 g/bhph (approximately 0.27 g/kWh) and for PM 0.01 g/bhph (approximately 0.0134 g/kWh), Table (bottom). Of course the new limits should be met with the minimum fuel consumption penalty.

2 From Euro 5 to Euro 6

A very important step towards reducing NO_x and particulates in recent years has been the further development of the combustion system. Optimized combustion chambers, improved fuel injection

and turbocharging with charge air cooling meant that it was possible for commercial vehicle engines to comply with the Euro 3 NO_x limits without any special exhaust gas aftertreatment. However, by the time Euro 4 came into being these techniques were, for the most part, no longer sufficient. To meet the new standards additional measures were required.

In terms of internal engine measures, however, it is not possible to minimize both NO_x and PM emissions at the same time (the NO_x/PM trade-off). A viable method of achieving this goal is to minimize one component inside the engine, for example NO_x, and the other outside the engine: in this case the particulates, using a particulate filer. Conversely, reducing particulates by measures inside the engine means that NO_x reduction has to take place downstream of the engine, for example by means of the process of selective catalytic reduction, SCR.

Behr worked together with engineering consultant AVL to investigate the NO_x reduction potential of SCR and cooled exhaust gas recirculation (EGR) technology. The findings indicate that both SCR and cooled EGR are viable options for Euro 5, **Figure 1**.

Euro 6 will require enhancements to the Euro 5 technology, as illustrated in **Figure 2**. Possible concepts are:

- SCR: Selective catalytic reduction, normally combined with single stage charge air cooling.
- EGR: Cooled exhaust gas recirculation combined with two stage turbocharging with intercooling. The exhaust gas cooling also takes place in two stages: a 1st stage of high temperature exhaust gas cooling (HT-EGR), and a 2nd stage of low temperature exhaust gas cooling (LT-EGR).
- SCR plus EGR: combinations of SCR technology and cooled exhaust gas recirculation are also possible. Boosting takes place in a single stage and exhaust gas cooling is a two stage process with high and low temperature stages (HT and LT stages). Other combinations are also possible. However, the common feature in all of these is that they are complex, expensive and require considerable space.

All systems require a diesel particulate filter (DPF) to reduce PM emissions.

3 Selective Catalytic Reduction

The SCR technology already used in Euro 4 and Euro 5 systems for commercial vehicles is based on the addition of urea in the form of an aqueous solution (Adblue) to the exhaust gas flow. Hydrolysis of the urea produces ammonia, a NO_x reducing agent which converts the NO_x into steam and nitrogen in a special catalytic converter. The complete exhaust gas aftertreatment system in this case consists of a diesel oxidation catalytic converter (DOC), a DPF, a hydrolysis catalytic converter (HC), a SCR catalytic converter (SCR cat) and trap catalytic converter (TC), and the Adblue tank and a metering unit.

However, the extremely low Euro 6 and US '10 limits probably cannot be met with catalytic NO_x reduction alone. This is because of the new test cycles for measuring the emissions. Instead of the ETC (European Transient Cycle) currently specified, for Euro 6 it is likely that the new WHTC (World Harmonized Transient Cycle) will be used. This cycle results in lower engine speed and load overall and, therefore, lower exhaust gas temperatures.

However, low exhaust gas temperatures reduce the generation of ammonia from the urea solution. Additionally, at low temperatures the catalytic converter also loses some of its efficiency. Thus the

Table: NO_x and particulate emission limits for heavy duty trucks (> 3.5 t) for Europe (top) and the USA (bottom)

Phase	Introduction date	NO_x [g/kWh]	Particulate [g/kWh]	Test cycle
Euro 3	October 2000	5.0	0.10 (0.16)	ESC (ETC), ELR
Euro 4	October 2005	3.5	0.02 (0.03)	ESC (ETC), ELR
Euro 5	October 2008	2.0	0.02 (0.03)	ESC (ETC), ELR
Euro 6*	2013	0.4 – 0.7	0.01	WHTC, WHSC

ESC: European Steady State Cycle
ETC: European Transient Cycle
WHSC: World Harmonized Steady State Cycle
ELR: European Load Response Test
WHTC: World Harmonized Transient Cycle
Values in parenthesis: ETC
Introduction date for new type approvals; for all type approvals normally one year later
Limit values for CO and HC not shown here
* Euro 6 not defined specifically, decision expected in 2008

Phase	Introduction date	NMHC + NO_x [g/bhp-hr]	NO_x [g/bhp-hr]	Particulate [g/bhp-hr]	Test cycle
US'98	January 1998	-	4.0 (5.36)	0.10 (0.134)	HD-FTP
US'04	January 2004	2.5 (3.35)	-	0.10 (0.134)	HD-FTP, SET
US'07	January 2007	-	1.2 (1.61)	0.01 (0.0134)	HD-FTP, SET
US'10	January 2010	-	0.2 (0.27)	0.01 (0.0134)	HD-FTP, SET

HD-FTP: Heavy Duty Federal Test Procedure
SET: Supplemental Emission Test
Values in parenthesis: g/kWh (conversion factor: 1 g/bhp-hr = 1.34 g/kWh)
Limit values for CO and HC not shown here

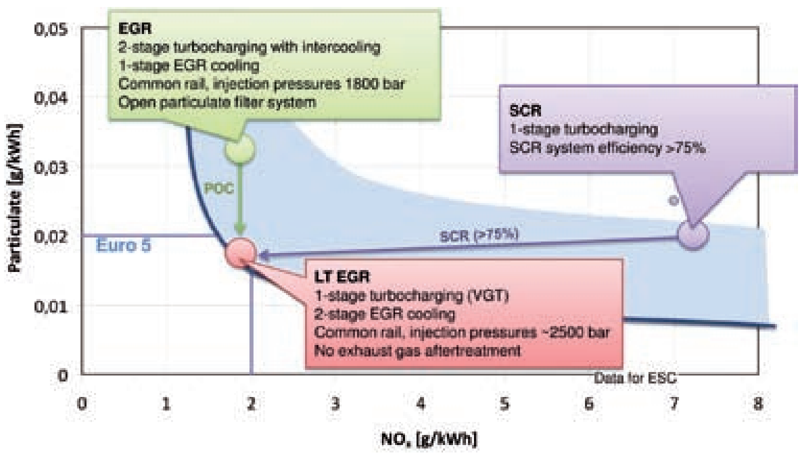


Figure 1: Technologies for Euro 5 – state of the art for the NO_x/PM trade-off

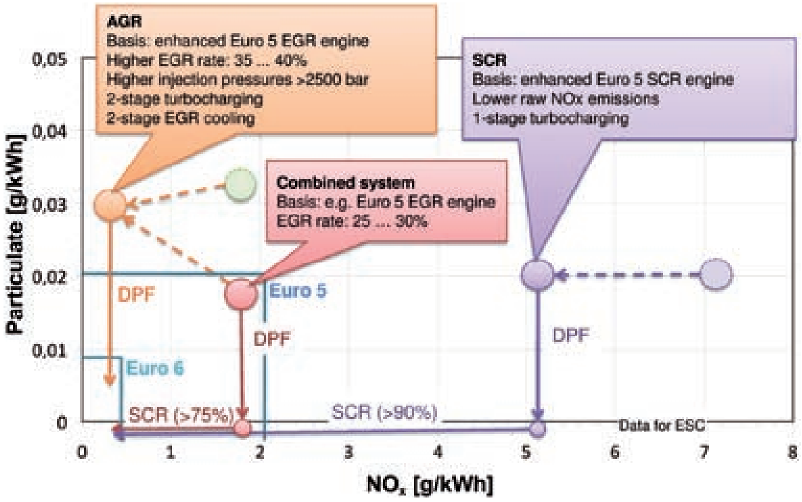


Figure 2: Technologies for Euro 6 – enhancements based on Euro 5

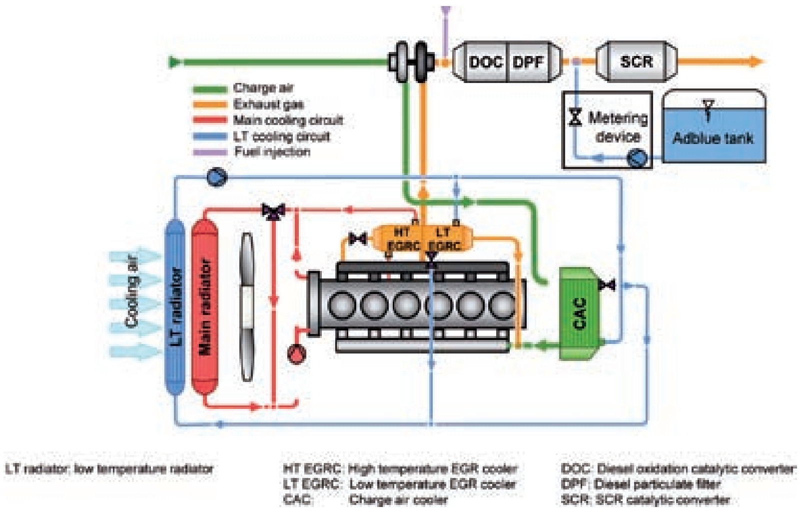


Figure 3: Combined system for Euro 6: EGR and SCR

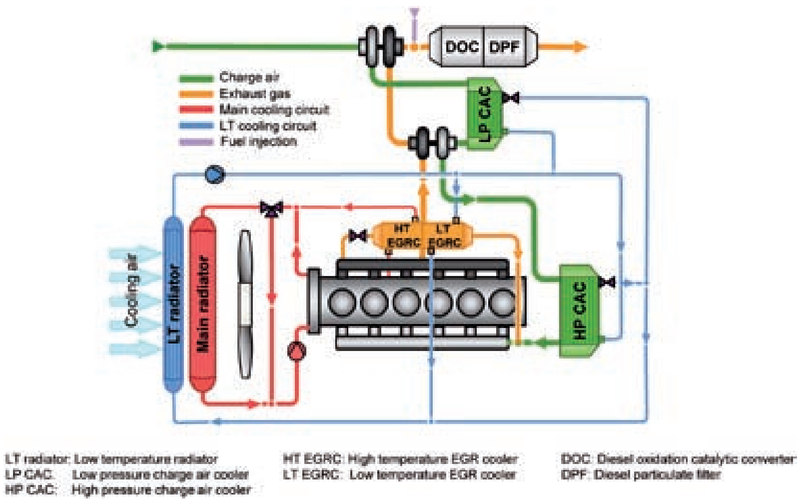


Figure 4: Potential two-stage EGR system for Euro 6

NO_x conversion rate is limited in two ways. In addition, the WHTC includes a cold test which further reduces the rate of conversion in the first part of the cycle. The resulting increase in NO_x emissions probably cannot be offset in the second hot parts of the test.

The transition from Euro 5 to Euro 6 requires an 80 % reduction in NO_x emissions. If this objective is to be achieved with selective catalytic reduction alone, the efficiency of the technology will have to be significantly increased, from around 75 % today to more than 90 %. That is not all: to offset the temperature effect from the new test cycles as described above it will be necessary to further boost the efficiency of the SCR system. Accordingly, it may be difficult to meet Euro 6 and US '10 using SCR alone.

One possible method for achieving the Euro 6 legislation would be to combine SCR and EGR technology, Figure 3. Since cooled EGR means less NO_x is produced in the engine, there is also less NO_x to be converted by catalytic reduction in the exhaust system. The drawback of this combined system, as mentioned previously, is its size and complexity.

4 Exhaust Gas Recirculation with Two Stage Cooling and Two Stage Turbocharging with Intercooling

4.1 Two Stage Exhaust Gas Cooling

Exhaust gas recirculation reduces the oxygen concentration of the cylinder charge, thus reducing the speed and temperature of combustion. Since the rate of NO_x formation is exponentially dependent on the combustion temperature, cooled exhaust gas recirculation is associated with a significant reduction in NO_x emissions. Cooling the exhaust gas also improves cylinder filling and reduces thermal stress on the engine components.

With cooled exhaust gas recirculation, some of the exhaust gas is diverted upstream from the turbocharger turbine and routed to the exhaust gas cooler via an EGR valve. In the case of two stage cooling, Figure 4, the first cooling stage is high temperature cooling (HT EGRC), the cooling medium is the coolant from the main cooling circuit, and in the second cooling stage (low temperature stage,

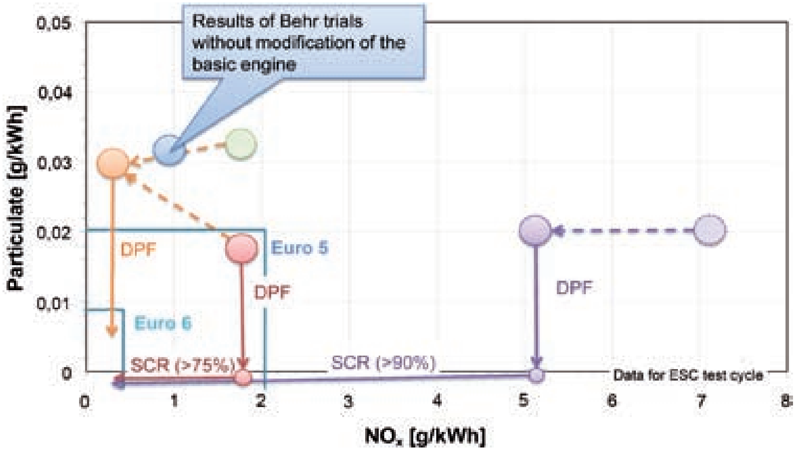


Figure 5: Potential of LT-EGR with respect to Euro 6

LT EGRC), it is the coolant from a low temperature circuit. To prevent the coolant from boiling in the first cooling stage, the exhaust gas and coolant flow in the same direction; the second stage operates in counterflow mode, which improves the cooling performance.

4.1.1 Self Cleaning of the EGR Cooler

A major advantage of two stage exhaust gas cooling – as compared with single stage cooling – is the self cleaning action of the EGR cooler and thus the stabilization of its cooling performance over the life of the cooler. This cleaning action is a consequence of the formation of condensation in the exhaust gas cooler. During the combustion, 1.26 kg of water for every 1 kg of diesel fuel is produced. Some of this steam condenses in the EGR cooler, where the condensation washes the deposits off the tubes of the cooler.

4.1.2 Cooling by Evaporation

Along with this self cleaning action, exhaust gas condensation also reduces the in-cylinder temperatures: firstly by the cooling effect from the evaporation of the charge air exhaust gas mixture and secondly by cooling due to evaporation of the intake air in the cylinder.

Cooling due to evaporation occurs when the condensate in the exhaust gas mixes with the dry charge air and evaporates. The heat required for this to happen comes from the charge air exhaust gas mixture, resulting in a fall in temperature of approximately 10 K. Because of the high dew point of steam, this cooling action occurs at high temperatures, for example 40 to 60 °C.

The exhaust gas condensate evaporates in the intake air but not completely: some water is remains and is conveyed with the intake air into the cylinders, where it evaporates in the compression phase. This second cooling effect limits the increase in the charge temperature during compression, lowering combustion temperatures and, therefore, NO_x emissions.

4.2 Two Stage Turbocharging with Intercooling

Cooling the charge air while keeping maximum cylinder pressures unchanged results in higher performance, lower fuel consumption and less formation of NO_x. In the LP and HP charge air coolers, Figure 4, the charge air, after being heated in each of the two compression stages, is cooled. The cooling of the charge air between the compressors, hence the term “intercooling”, improves the efficiency of the second compressor.

4.3 Results

In various tests Behr together with AVL has already reduced NO_x values to about 0.8 g/kWh over the test cycle. However, the optimum has still not been reached. It might be possible to reach the Euro 6 limit, which is likely to be in the region of 0.7 to 0.4 g/kWh, **Figure 5**. It should, however, be noted that low temperature EGR is likely to be successful only in combination with two stage turbocharging and advanced fuel injection systems.

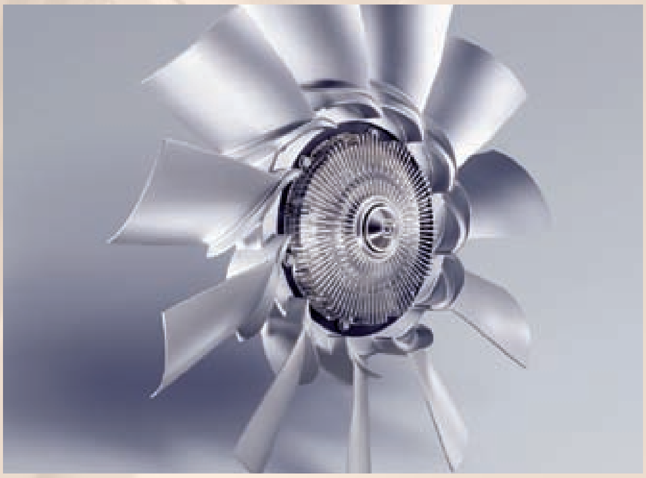
5 Conclusions

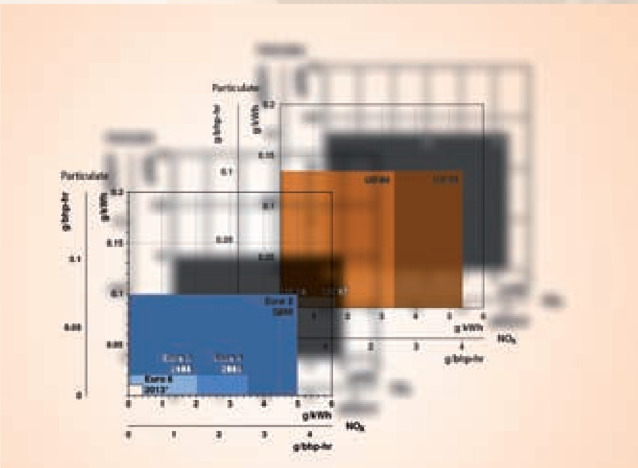
The Euro 6 and US ’10 emissions limits are unlikely to be met using SCR technology alone. Cooled exhaust gas recirculation (EGR) will be part of the emissions solution. A combination of SCR and EGR is possible but may have weight, packaging, complexity and cost penalties.

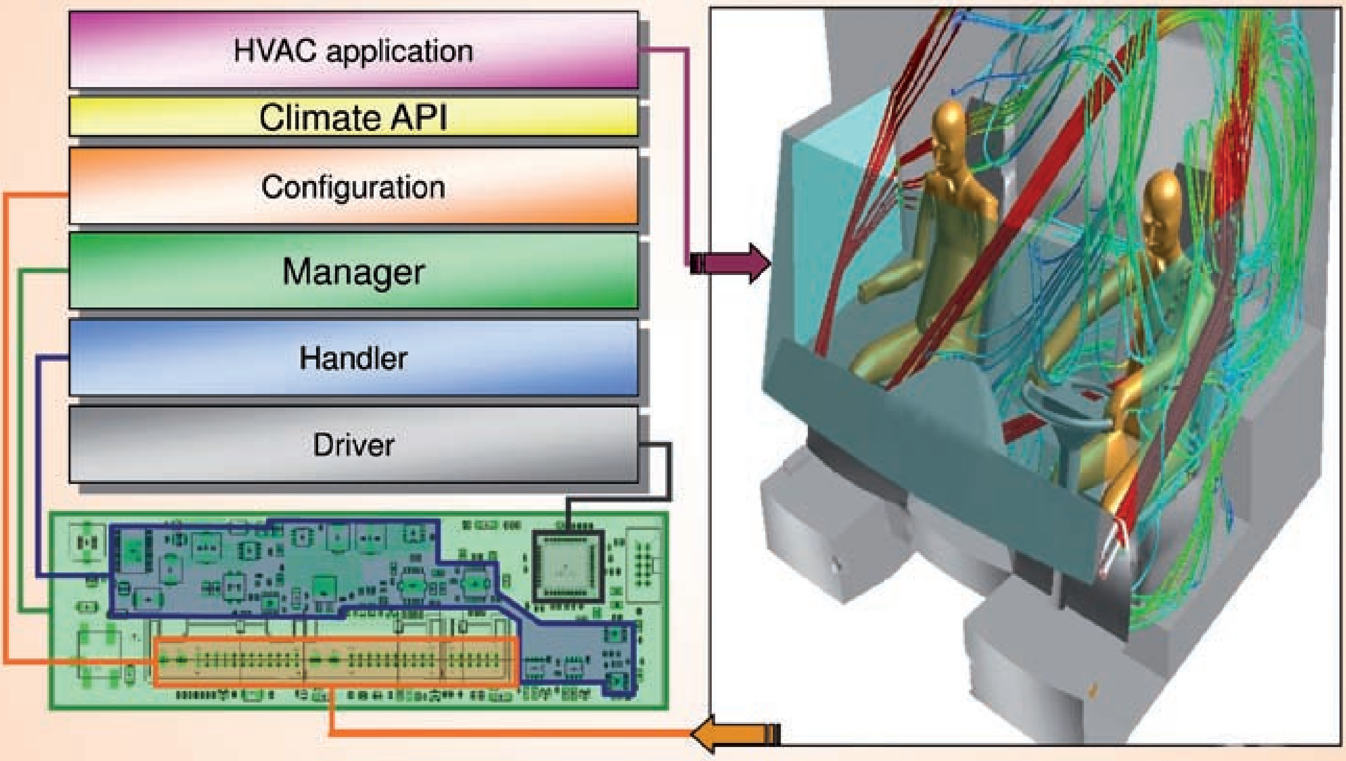
A possible solution is the two stage cooled exhaust gas recirculation process described above, combined with two stage turbocharging. This system possibly has the potential to achieve the potential Euro 6 limits. It should be noted that cooled EGR will also play a key role in enabling off-highway vehicles meet future emissions limits. ■

Special Behr

Thermal Management for Trucks







Ergonomics and Operating Concepts for Trucks

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort.

The Author

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1 Behr Hella Thermocontrol

Since the formation of BHTC as a 50/50 joint venture by the Behr and Hella groups in 1999, the company has grown rapidly and today is one of the world's leading manufacturers of control heads for HVAC systems. The product portfolio also includes control units (ECUs) for electric auxiliary heaters, blower controllers, and A/C sensors. The company counts the world's largest car and truck makers among its customers, and serves them not only from its parent plant in Lippstadt, but also from its subsidiary plants in North America, India, China, and, more recently, also in Japan. The BHTC mission is to provide "Comfort in Motion" by creating products that play a key role in ensuring optimum cimate comfort in cars and trucks.

2 Cars and Trucks: Differences in Climate Control

In recent years, there has been a sharp increase in comfort requirements for truck cabs. The driver's space is now recognized as a proper workplace. Ever more importance is accorded to the climate in the vehicle cab. Features that have long been standard in passenger cars have for some years now also been making their way into commercial vehicles. Today, no manufacturer can ignore its customers' demands for greater climate comfort. However, optimum climate comfort benefits not only the driver, but also all other road users as well: high interior air quality and a pleasant cab climate improve drivers' performance and help them to concentrate on the traffic.

Comfort is not only enjoying a pleasant climate in the driver's cab, but also the rapid response of the climate control system to changing climatic conditions. The system can thus ensure constantly mist-free windows and draft-free temperature control of the driver's workplace. The dash vents and the ventilation blowers are controlled in such a way that virtually no condensation forms on the windshield and side windows, and unwanted drafts are avoided.

Sensors measure the temperature at each of several points in the A/C system, and compensate for the influence of incoming solar radiation that falls directly onto the non-ventilated cabin temperature sensor. The climate control system can thus react quickly to changes.

Nevertheless, there are differences in the air conditioning of passenger cars and commercial vehicles that make the direct adoption of HVAC modules and control concepts from passenger cars impossible, **Figure 1**:

- A larger cab volume, and higher cabs.
- Commercial vehicles usually have a large, but vertical windshield. Compared with passenger cars, this results in less heat from solar radiation entering the cab in the middle of the day.
- Generally, the windows do not feature heat-absorbing glass comparable with that of passenger cars, and this results in a greater influx of heat when the sun is low.
- Cold outside temperatures, if they are not adequately compensated for by air conditioning, can result in an unpleasant flow of cold air at the windshield, leading to cold arms and thighs.
- Increased use as a result of ever denser traffic and frequent changes of drivers call for more user-friendly controls, that means it is important for the operator to quickly and intuitvely understand how the air conditioning system works.
- Owing to the greater movement range of the driver's seat, the operating controls must be larger and clearer in terms of their functional classification.
- The effect of the center air vent in the instrument panel is generally not so intense, owing to the greater distance to the driver.
- All system components must be designed for a longer service life.
- Today, some passenger cars have multi-zone climate control systems that must react more quickly to the changing amounts of incoming solar radiation due to the large sloping windows.
- Long-range trucks have a sleeper cab, which, in stationary operation, increasingly requires not only controllable heating, but also air conditioning; see the presentation on no-idle air conditioning.
- Passenger car platforms with high unit numbers of individual model series require specific climate control hardware and software components that are based on a standard module set. Control heads for truck air conditioning systems are also designed for platforms, but because the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software, **Figure 2**.

3 The New Climate Control System for the MAN TGX

For the design of the A/C control heads and ECUs for the air conditioning systems for the new MAN TGX, a modular concept was adopted from the outset. This concept makes a clear distinction between design and functionality.

The control head for the air conditioning system was thus integrated into the modern cockpit with significant space savings, and adapted to an individual design that meets demanding ergonomic and functional requirements. In all variants, mechanical Bowden cables from the control head to the HVAC system are dispensed with, and only six electric cables are used to connect the control head and ECU.

4 The HVAC Control Head

As the functionality of air conditioning systems increases, their operability often decreases. Especially in the case of commercial vehicles, owing to the long travel times with dense traffic, frequent changes of drivers, and the large movement range of the driver's seat, clearly identifiable and understandable controls are important.

We already provided an in-depth report on the link between operating ergo-

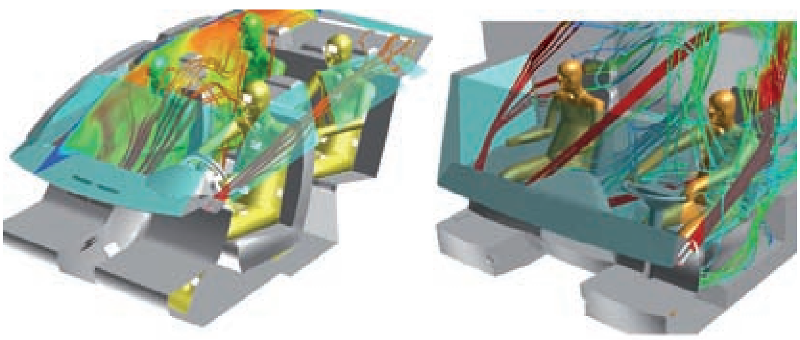

Figure 1: Cabin volume, layout and size of the windshield make up the big difference in the climate control between passenger cars and commercial vehicles

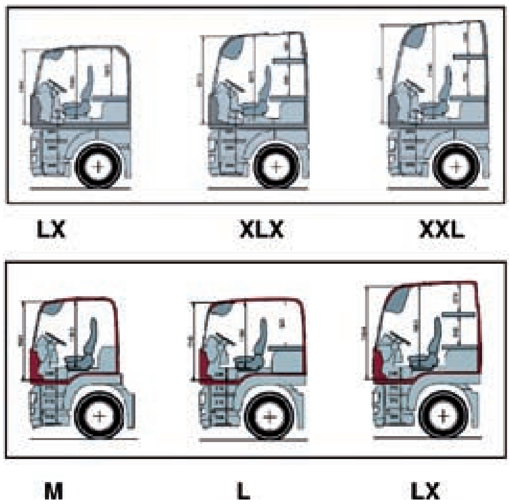

Figure 2: In commercial vehicles, the cabs' superstructures are very similar in their dimensions and form, these control heads do not require any model series-specific hardware or software

nomics and traffic safety and a operability studiy carried out with the Technical University of Munich in 2007. Inadequate ergonomics lead to significant risks in traffic situations. The results show that easily recognizable symbols are based on:

- symbols/graphics
- depictions of people
- depictions of seats
- a vehicle contour to back up the symbols
- a combination of text and symbols.

Whereby symbols that are not easily recognized often contain text with no symbols, abstract symbols, or symbols that deviate from the international ISA standard.

The control heads for the MAN TGX therefore reflect the state of the art in relation to operating ergonomics, **Figure 3**.

In the fully automatic air conditioning unit, the driver selects both the desired air distribution and the blower speed by means of two control dials. The driver sets the temperature by means of two buttons, and the selected temperature is shown in a display. In the simpler heating variant, the temperature is set using the left-hand control dial, while the blower speed is changed by means of two buttons. In this A/C control head, particular importance was placed on easily understandable operation and ease of identification of the symbols for the switches and the display by both day and night. This is particularly important for trucks since they are driven for much longer periods, and also at night. It was therefore important to have highly contrasting images and clarity of symbols. This requirement was satisfied in all of the device variants by means of fail-safe LED lights, high-quality plastics technology for the operating buttons, and lasered symbols. In this way, with backlit symbols, no light can escape from the button control panel. Drivers receive an unambiguous acknowledgement from the system via the display in all control head variants, and can thus give their full attention to the traffic.

In the automatic mode of the fully automated system, the blower output temperature adjusts itself independently according to the vehicle's boundary conditions.

All the necessary settings for the air conditioning in the driver's cab and the sleeper cab in the new MAN TGX und TGS vehicles can be operated using a maximum of ten buttons and two control dials. One control head is therefore used to control both the driving and stationary operation. A second control head in the rear is therefore not necessary.

In order to ensure that the device has a long service life and is robust, and requires no maintenance, a non-ventilated interior temperature sensor (ITOS), **Figure 4**, was also used instead of the customary ventilated interior temperature sensor. The cab temperature is measured using the robust and maintenance-free sensor, and this is compensated for by means of a customized control system taking into account the incoming solar radiation, and also the heating of the device itself.

5 The Air Conditioning ECU

In the MAN TGX, a standardized air conditioning ECU was used for the first time. Behr and BHTC are thus responding to customers' demands for ever-smaller packaging dimensions of the control head and an individual design of the instrument panel with maximum control functionality.

For the climate control, a functional separation of the ECU and the A/C control head was selected, **Figure 5**. The heart of the ECU is a printed circuit board of modular construction and of standard dimensions. Thanks to the standard printed circuit board, the dimensions of

Figure 3: The control heads for the MAN TGX / TGL reflect the state of the art in relation to operating ergonomics

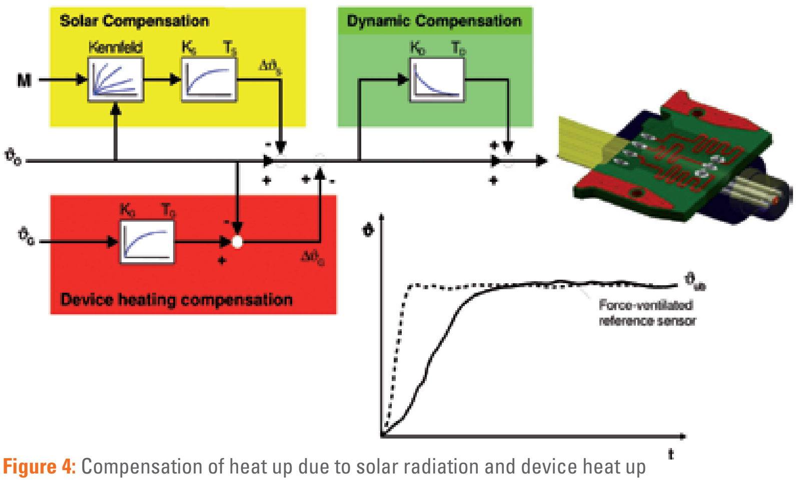

Figure 4: Compensation of heat up due to solar radiation and device heat up

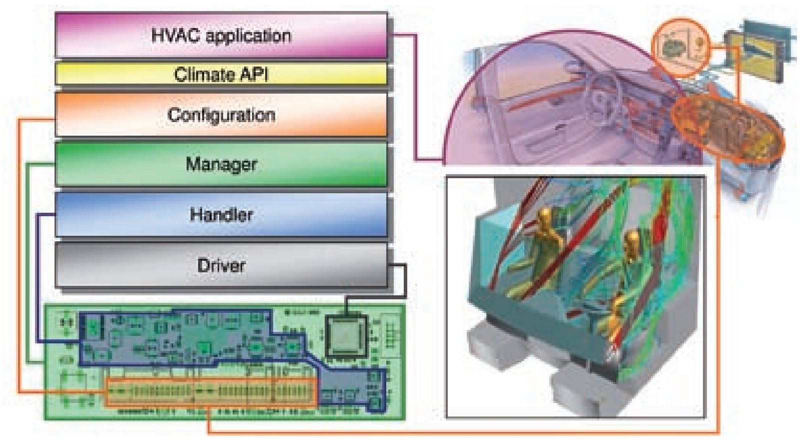

Figure 5: Architecture of the standardized air conditioning ECU – separation of function and design

the ECU and the connector plug are identical for all variants.

The ECU is installed in the vehicle in such a way that the HVAC module and ECU form a functional unit with short electrical connections. A mechanical coupling between the control head and the HVAC module is no longer required. In addition to the preferred mounting position on the HVAC module, other mounting locations in the vehicle are, in principle, also possible.

The open architecture and the less complex design of the control head give the customer more freedom in the design of the instrument panel in the vehicle than before, and better use is made of the existing space envelope. Other variants adapted to the customer's requirements can be obtained only by means of a different assembly and different programming of the processor. This reduces the development outlay required for variants, and cuts costs. The ECU is also flexible in terms of the interface to the customer's preferred data bus format.

6 Summary

Thermal comfort in the vehicle significantly increases road safety because the driver is under much less stress. This applies particularly in the case of trucks as proper workplaces. Whereas a few years ago there were still relatively few demands placed on air conditioning in the cab of a commercial vehicle, today no truck manufacturer can ignore the demands of its customers for greater climate comfort. Operation of the air conditioning unit must respect ergonomic considerations, so that drivers take advantage of all of the capabilities of the A/C system on the one hand, and are not distracted from the traffic by its operation on the other.

With the unit's design and operating concept, BHTC has satisfied the increasing demands for an A/C control head that is modern, efficient, and at the same time user-friendly.

Whatever the initial climatic conditions at the start of the journey, or however they change during the trip, the climate control system always ensures consistently comfortable and draft-free air conditioning, and thus avoids any additional stress for the driver.

A climate control system that is functionally and ergonomically designed using state-of-the-art processes thus plays a key part in reducing the stress on drivers, and, thanks to the comfortable cab conditions, helps them stay relaxed in every traffic situation.

Non-idle Air Conditioning for Enhanced Road Safety and Reliability

Transportation of freight by truck is very important for the functioning of the economy and society. As the driving condition of the driver plays a key role in this, it is essential to provide adequate thermal and acoustic comfort during rest periods. A non-idle A/C system that provides air conditioning both during journeys as well as during rest periods and when the windows are closed, improves driver recuperation. The driver is thus better able to concentrate and feels fitter and more refreshed.

The Author

Dr. Lubens Simon is chief of commercial vehicle climate systems development at the Behr GmbH & Co. KG in Stuttgart-Feuerbach (Germany).

1 Introduction

Transportation of freight by truck plays a key role in the functioning of the economy and society in all Western countries. It is even more important that this transportation takes place in a safe, reliable, and eco-friendly manner, and that it is cost-efficient. Drivers play a key role in achieving this: their health, ability to perform and to concentrate, in short: their driving condition. In order to maintain this condition at a high level for the entire duration of the journey, drivers require a workplace that is ergonomically designed and has a pleasant cab climate.

This involves a high level of thermal and accoustic comfort, which is important not only during the journey itself, but also when any stops are made, whether they are voluntary or involuntary. The thermal comfort is particularly important in driver rest periods, because otherwise the degree of recuperation is reduced. This applies especially to the sleeping phase, since drivers who are not well-rested pose a danger to themselves and to other road users. The infamous "miscrosleep," one of the greatest causes of accidents, is primarily due to inadequate or unrestorative sleep. Non-idle air conditioning, that cools the cabin also during the rest periods with windows closed, enhances the thermal comfort of the driver and thus his ability to concentrate.

2 Driver Survey on the Use of Non-idle A/C Systems

In 2006, Behr surveyed 500 truck drivers from different countries with different vehicles at a total of six rest areas along Germany's main highways. The aim of the survey was to find out how the drivers use the cab as a living space, and what the requirements of this living space are (with a focus on air conditioning), and also what the future requirements of the market are, and which product strategy can be developed from this information.

After this general questioning, 16 drivers were selected for a longer interview. These people formed a representative market cross-section of long-distance drivers who had a non-idle A/C system.

It was found that the great majority of the drivers believe that a non-idle air conditioning unit is important. Around 90 % of the drivers who did not have this sort of system in their vehicle would choose to have one. Since only one fifth of all long-distance trucks are equipped with non-idle vehicle air conditioning, there is a very high market potential. By contrast: parking heating systems are found in all heavy-duty trucks. A summary of the driver's views: Non-idle air conditioning systems ...

- ... are used in a similar way as parking heaters, and are valued just as highly by drivers
- ... are nevertheless available commercially only at a market level of 20 %
- ... are perceived as improving drivers' personal safety
- ... avoid engine idling, and thus prevent fuel consumption and engine wear
- ... should provide air conditioning at night for up to ten hours, and for up to two hours during the day with incoming solar radiation
- ... should provide automatically controlled air conditioning for the entire cab
- ... should not require any servicing or any initial activation.

According to this information, non-idle air conditioning systems have a high market potential. From these and further results of the survey, the following specifications have been provided:

Non-idle air conditioning systems should ...

- ... cool the cab during overnight stops for up to ten hours and for up to two hours during the day (even with strong incoming solar radiation)
- ... provide draft-free cooling of the entire cab (not only the space above the bed)
- ... have automatic temperature control
- ... be reliable and easy to operate
- ... not require any maintenance; the charging of the energy storage devices (cooling battery or battery pack) should occur automatically
- ... be interfaceable with an automatic fresh air supply.

The requested hours of operation and performance can be fulfilled by electrical systems. Also, roof units will fulfill the expectations on non-idle a/c units. The non-idle air conditioning systems currently available on the market are still highly inadequate compared with what drivers want in terms of both their technology and their performance. In order to satisfy all of the requirements of the users, Behr has set itself the following additional design objectives for non-idle air conditioning systems:

- a low current draw in order to allow battery pack operation
- installation in existing roof openings for aftermarket applications
- satisfy truckmakers' installation requirements, specifically in terms of quality, durability and reliability and integration into the operating system architecture.

On the basis of these design objectives, an electric non-idle air conditioning unit

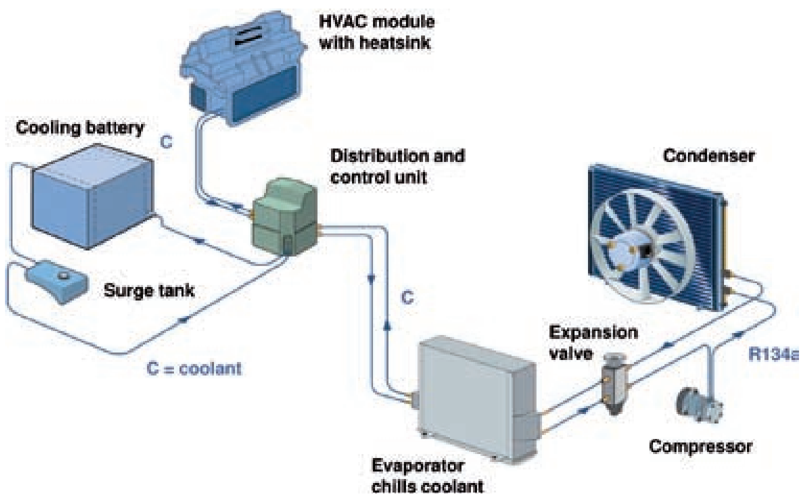

Figure 1: System diagram of the non-idle air conditioning with cooling battery from MAN

in the form of a roof unit was designed and constructed as a demonstration model, in addition to the non-idle air conditioning system with a cooling battery that is already in series production. Design of a rear wall unit is currently under way.

3 Technical Features of the Cooling Battery System

The non-idle air conditioning system with a cooling battery is fully integrated in the vehicle, and replaces the conventional engine-driven air conditioning system. The system has a secondary circuit **Figure 1**. In the charging phase, a conventionally operated refrigerant circuit intensely cools a liquid refrigerant in a special evaporator. This coolant, controlled by the distribution unit, cools both the heat sink in the HVAC module as well as the contents of the cooling battery, which therefore freezes. The heat sink replaces the conventional evaporator in the HVAC module; it cools the cab air during the journey, and during breaks in the journey. In the non-idle A/C system, the refrigerant circuit is in the resting state. By means of the circulating refrigerant, the heat from the vehicle cab is slowly transferred to the cooling battery, where the frozen content of the cooling battery is liquefied. The system with the cooling battery is fitted as standard in the heavy commercial MAN vehicles TGA (since 2003) and the more recent TGX from MAN (since 2007).

4 Technical Features of the Roof Air Conditioning Unit

This plug-in 24-V unit can either be factory fitted or retroffited on the aftermarket. The unit is made up of an electrically operated, conventional refrigerant circuit that essentially consists of a compressor, condenser with fan, receiver, blower, and evaporator with expansion device, **Figure 2**. These components are housed in a single module that projects into the roof opening of the vehicle. Inside the cab, a screen allows drivers to see only the air inlet and the air outlet openings, and the control head. **Figure 3** shows a cross-section through the roof unit installed in the ceiling of the cab, and how it works.

The unit is operated with recirculated air. Control of the fresh air supply is integrated in the control system of the engine-driven air conditioning unit. For the power supply, in addition to the starter batteries, an additional battery pack, for example consisting of lead-gel batteries, must be provided in the vehicle. Some of today's systems are, in fact, powered by conventional starter batteries, but these are not really suitable for operating non-idle air conditioning systems because they are designed to deliver a high current over a short period of time. The non-idle air conditioning system must, however, be supplied with power over several hours. In a nine-hour operation, the battery is almost completely drained, and thus needs to be recharged. If a starter battery was frequently charged and drained, its capacity would quickly be reduced even after 15 such cycles to under 40 %. Starter batteries are therefore unsuitable for this application.

Lead-gel batteries, by contrast, are cycle-proof, that means they can be repeatedly recharged to a high capacity.

The roof air conditioning unit provides sufficient power to air-condition the cab, even with incoming solar radiation during the day. The two-hours-per-day period of operation determined from the driver survey is not, however, the critical value for the battery pack, but instead night operation of up to ten hours. In the case of an average power consumption of the unit of only 400 W, this would require, for example, a battery pack with four standard size traction batteries. The low power consumption of 400 W is the result of the system's exceptionally high efficiency.

Figure 4 uses measured values from the Behr climatic wind tunnel to show the course of air conditioning at night

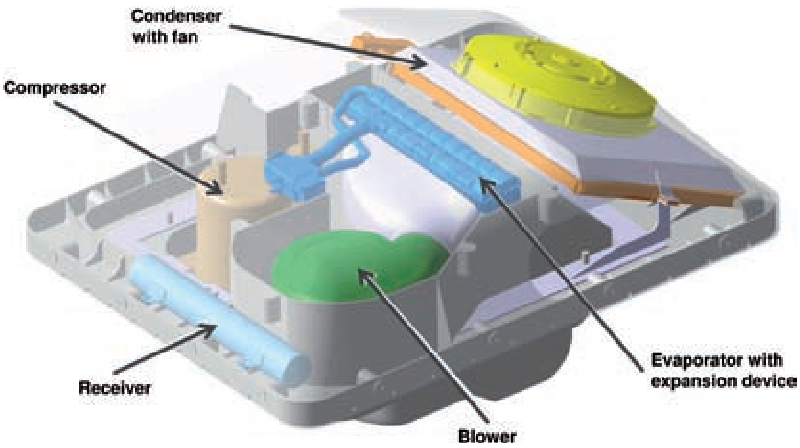

Figure 2: Schematic depiction of the electrial roof air conditioning unit

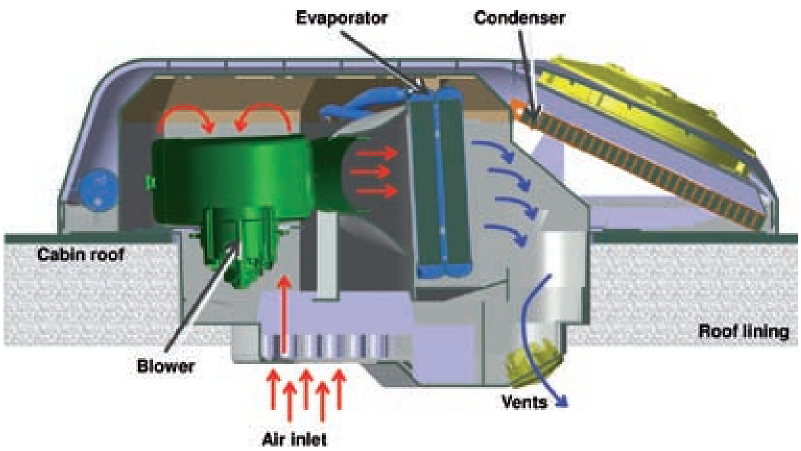

Figure 3: Side view of the electrial roof air conditioning unit

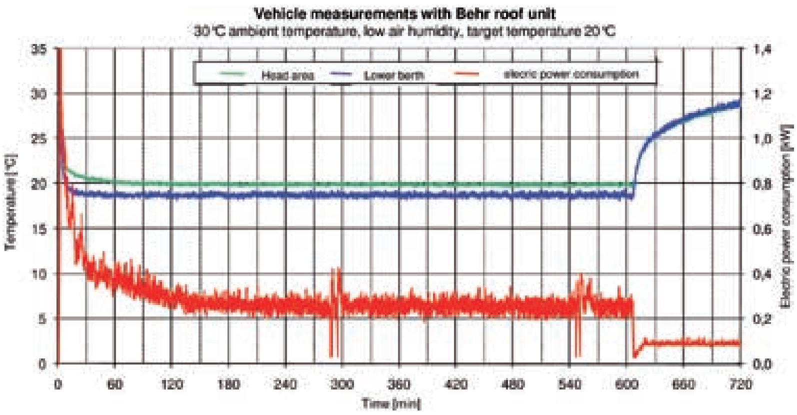

Figure 4: Cool down and power consumption of the electrial roof air conditioning unit at night

with an outside temperature of 30 °C. The target temperature of 20 °C is very quickly achieved and maintained, thanks to the temperature control over the ten hours. The power consumption is almost always less than 400 W.

5 Advantages of the Electrical System

The electrical system has two advantages over the system with the cooling battery: for one thing, drivers can access the cooling capacity at almost any time, because the batteries can store the power supplied by the generator for a long time. They therefore do not need to plan the charging or even to initiate it, since this happens automatically. During the journey, the battery pack is then constantly maintained in the fully charged state. In the system with the cooling battery, the charging of which is initiated manually, it is not possible to exclude the possibility that the driver may one day forget to initiate the charging, or may initiate it too late. If cooling is then required, there may be no or insufficient cooling capacity available. This point was also mentioned in the driver survey, which then also led to the call for an automatic charging of the cooling battery or battery pack.

The second advantage of the electrical system is that, with the battery pack for the non-idle air conditioning unit, additional electrical devices can also be operated, for example a television, computer, microwave oven, or coffee machine. Because the starter battery need not be used to do this, it therefore cannot be drained accidentally.

6 Behr's Development Capacity

As an original equipment manufacturer and systems supplier of passenger car and truck air conditioning units, Behr designs not only the HVAC modules, but also the control heads and associate software, working with joint venture companies such as Behr-Hella Thermocontrol (BHTC). This calls for expertise in the communication processes in the vehicle and for close collaboration with the vehicle manufacturers, for example for the construction of an interface between the engine-driven and non-idle air conditioning systems. Such an interface is required, for example, when the fresh air supply to the cab is to be taken over by the engine-powered A/C system instead of the non-idle air conditioning unit. This is particularly desirable when the truck's engine-driven A/C system is equipped with active carbon filters. In this case, the cab is supplied with filtered, gas-free air that increases drivers' safety when they are asleep. Generally, the fresh air is supplied at intervals, activated, for example, by a timer. The timed control saves battery power, but still guarantees an adequate supply of fresh air.

7 Summary

Non-idle air conditioning systems have considerable market potential, comparable with that of parking heaters, with which almost 100 % of long distance trucks are equipped. Behr's electrical units satisfy all relevant performance requirements, and have proven to provide a higher cooling capacity and higher efficiency than all comparable systems. A further advantage of the Behr units is their reliability, because the system components were designed specifically for use in trucks, and are sourced from series production of vehicle air conditioning units. ■

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US ‘10 envisages another drastic reduction in NO_x emissions for commercial vehicles.

Measures for Satisfying Future Exhaust Emissions Standards in Special-purpose Vehicles

1 Behr Industry

When Behr Industry was founded in 1990, the objective was to cater to special markets in the engine cooling and air conditioning sectors. The justification for this was that technical and legal requirements were made with respect to the components and systems of off-highway vehicles that were completely different from those for the passenger car and commercial vehicle markets – requirements that cannot be satisfied by simple modification of an existing component or of an existing system.

The split of Behr Industry and Behr GmbH & Co. KG essentially reflects our customer structure, since Behr's customers often operate in different market segments, and under different names. Today, Behr Industry is active in the markets for buses, heavy-duty engines, railway vehicles, aircraft, construction and agricultural vehicles, electronics, military products, and gensets (that means diesel-engine driven generators for generating electricity). The most important requirements are:

- The smaller production volumes or even single unit productions, also mean, that different development procedures, manufacturing technologies, and logistic concepts are necessary.
- The Euromot, EEV, and Tier X legislation governing emissions and CO_2

emissions is very similar to the Euro 5/6 and US 'XX standards from the car and truck vehicle sectors – only time-displaced by about three years.
- Other constraints on cooling requirements, installed position, and the available installation space.
- In the special-purpose vehicles, the components and systems are exposed to different stresses: fouling through mud, dust, and fibers results in different focuses for the development of heat exchangers. In some shipbuilding applications, cooling takes place using the seawater itself. The corrosive action of the saltwater is countered with special stainless steel.

2 Small-scale Series Production

For example for buses, small-scale series production specifically means annual volumes of approximately 500 to 3000 units. In the case of railway vehicles, the figure can be as low as just five to 100 units per year. Behr Industry must therefore use other processes for manufacturing radiators and coolers and for assembling complete cooling systems. Semi- or fully automatic production equipment can be used only rarely, and the costs of die-casting or functional plastic components often cannot be redeemed, owing to the high capital costs involved. Flexible systems are called for that require little or no capital expenditure; however, these demand higher manual production outlay and highly skilled manufacturing staff. Behr Industry also endeavors to carry over products or components from high-volume series production and integrate them (for example buses and tractors) in order to take advantage of the cost benefits of large-scale series production. This significantly reduces R&D expenditure, validation requirements, and the risk of failures in the field.

Behr Industry also employs the general Behr production standards and development tools and tests and develops its products in the test facility of the parent company, and uses the same simulation tools (FE analyses, CFD calculations, BISS). This makes the development of new products specifically catering to special market requirements efficient and competitive.

3 Exhaust Emissions Standards

The debate over the lowering of CO_2 emissions and pollutant emissions also involves the special markets. Euro 5 / US 10 envisages another drastic reduction in NO_x emissions for commercial vehicles. The corresponding standard for the off-highway sector is Euromot stage IIIB / Tier IV A, and will come into effect approximately three years after Euro 5 / US 10. The limits for NO_x and particulate emissions are not much different from those of commercial vehicles: Euromot stage IIIB envisages a reduction of nitrogen oxide emissions to 2 g/kWh, and of particulate emissions to 0.025 g/kWh (Euro 5 specifies 2.0 NO_x and 0.2 PM).

The exhaust emissions standards for off-highway vehicles in the USA are similar. The standards that are similar to the US07 and US10 standards are the Tier 4a and Tier 4b standards, which will come into effect at the same time as Euromot stage IIIB, that means three years later.

In the bus market, we find a special situation; here, the EEV (Enhanced Environmental Friendly Vehicle) preliminary standard was introduced. EEV is not a mandatory limit, but rather a voluntary standard that is virtually no different from Euro 5 in terms of the limits on NO_x and particulate emissions. EEV engines essentially already satisfy the Euro 5 standard that will be in force from 2009. The environmental awareness of the bus operators, in particular in large cities, leads to their voluntarily complying with special limits as per EEV.

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In order to comply with the exhaust emissions regulations and to save fuel in off-highway applications, as in the case of commercial vehicles, systems such as cooled exhaust gas recirculation or two-stage turbocharging are used, **Figure 1**. Here, too, this similarly leads to increasingly complex cooling systems every time the exhaust emissions laws are tightened further. Higher charge air temperatures and pressures and quantities of heat in the coolant call for new solutions for heat exchanger design. The integration of cooled exhaust gas cooling and indirectly cooled charge air requires considerable systems expertise in order to be able to guarantee the necessary cooling within the special constraints of the off-highway market.

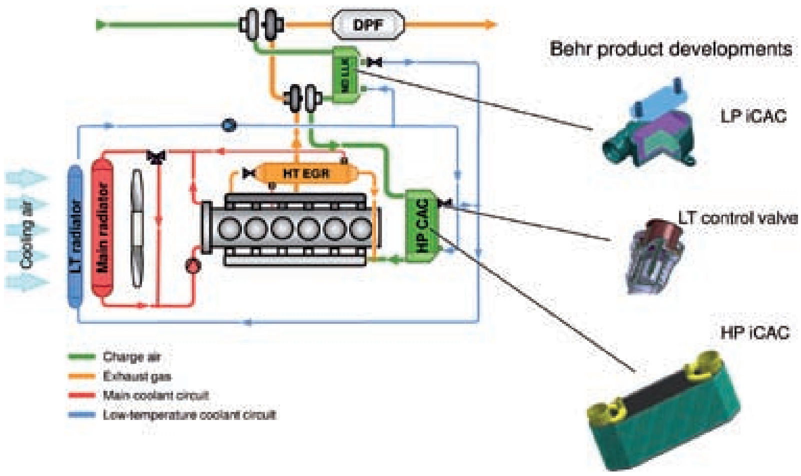

Figure 1: Schematic representation of a two stage turbocharging with indirekt charge air cooling

4 Fouling

A distinctive feature of special-purpose vehicles is their use in very different areas of application: mines, fields, rails, water, construction sites, forests, or garbage dumps. Fouling on the external surface through which cooling air passes thus takes very different forms. Sand, dust, oils, pollen, leaves, plant debris, grass, litter, and many other soiling agents in every possible combination accumulate on the air side inside the radiator and between the fins, Figure 2. This leads to a higher air-side pressure loss and restricts the flow of cooling air. The radiator can no longer provide the desired cooling power to the engine, and engine performance decreases accordingly.

Here, conventional radiators with louvered corrugated fins cannot be used. Behr Industry has developed special cooling air fins specifically for these applications. Unlike conventional fins, these do not have any louvered structure on their surface; instead, they are flat or corrugated. In car or truck radiators, these louvers serve to improve heat transfer between the cooling air and the cooling water, because the air does not pass through the fins in a laminar flow, but instead turbulence is produced on the louvers, Figure 3. However, a lot of dirt particles collect on these louvers that cannot be removed by using compressed air, for example. If there are no louvers, dirt particles can be blown away against the direction of flow.

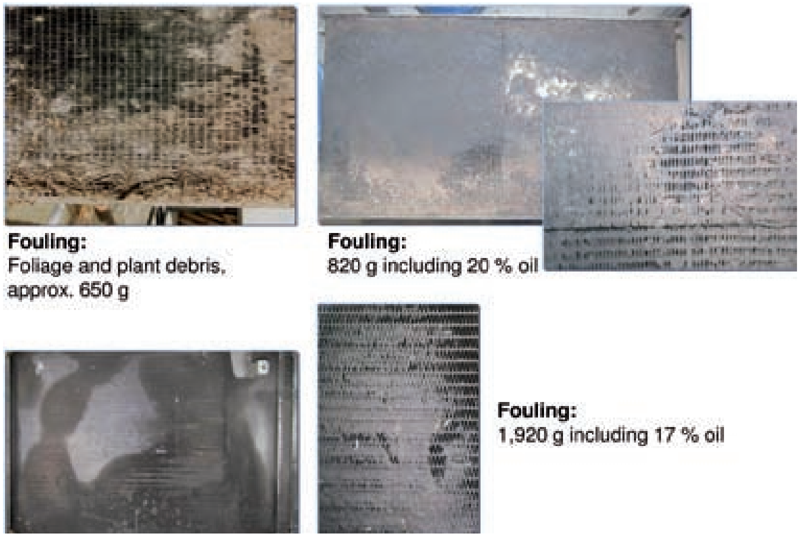

Figure 2: Representative examples of different foulings as found in off-highway applications

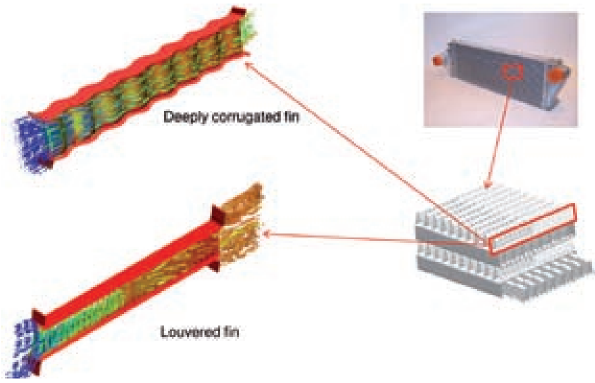

Figure 3: Comparison of a deeply corrugated fin and a louvered fin

In order to understand the mechanisms of fouling and to draw the appropriate technical conclusions, Behr Industry has been working closely with a number of institutes for several years. Figure 4 and Figure 5 show the results of tests on different cooling air fins that were realized in collaboration with the ILK Dresden (Institute of Air Handling and Refrigeration Technology in Dresden). These tests investigated to what extent the pressure drop on the cooling air side is dependent on the dust concentration and the fin used. It was found that the flat fin has the smallest pressure drop. Figure 5 shows the results of similar tests, but under more realistic conditions using fibers as the fouling agent. A flat fin, a staggered fin and a louvered fin were exposed to fibers during usage and the cooling air side pressure drop was measured over time. After a predetermined cycle had been completed, the fins were cleaned with compressed air. It is observed that the pressure drop in the louvered fin is worse after every cleaning cycle compared with the flat fin and the fin with deep corrugations. This is because fibers penetrate deep inside the fins, and, in the louvered fin in particular, can then no longer be removed. Therefore, over time, the radiator with the louvered fins becomes clogged up, and can no longer be cleaned.

Of course, the efficiency of the radiator decreases with the soiling of the louvers. Together with our customers, we must therefore arrive at a compromise between the prevention of fouling and the performance density of the radiator.

Furthermore, the arrangement of the individual coolers (radiator, charge air cooler, etc.) can play a role in minimizing the susceptibility of the cooling module to fouling. In conventional radiators, the individual radiators are arranged one behind the other ("face to face"). The problem here is that dirt particles may pass through the first radiator and become caught in the second one. For cleaning, the cooling module would have to be dismantled. To avoid this, the radiators can be arranged next to one another ("side by side"), so that all of the faces can be cleaned from the outside. Alternatively, the frame of the cooling module can also be designed to swing open, in order to facilitate cleansing of the second radiator, Figure 6.

5 Systems Expertise

All of these requirements must be implemented for a small market that individually caters to specific customers. Behr Industry provides not just the coolers and

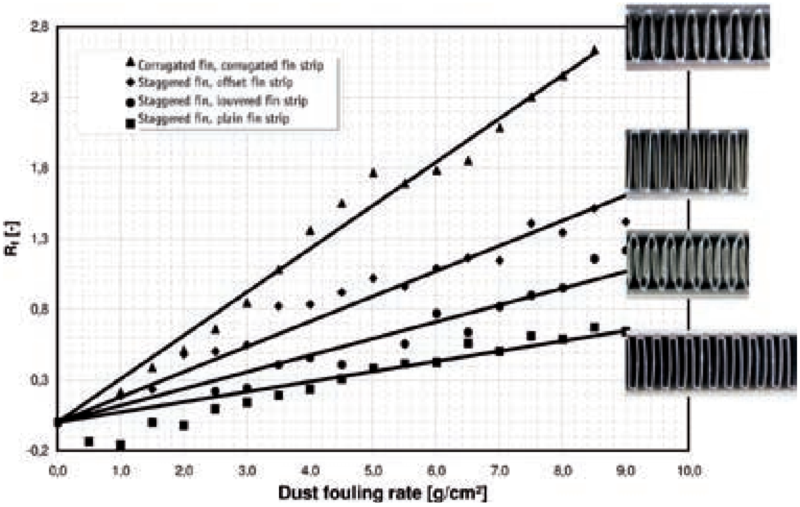

Figure 4: Fouling: Impact of dust on the pressure loss in coolers. Investigations performed by ILK Dresden on behalf of Behr Industry

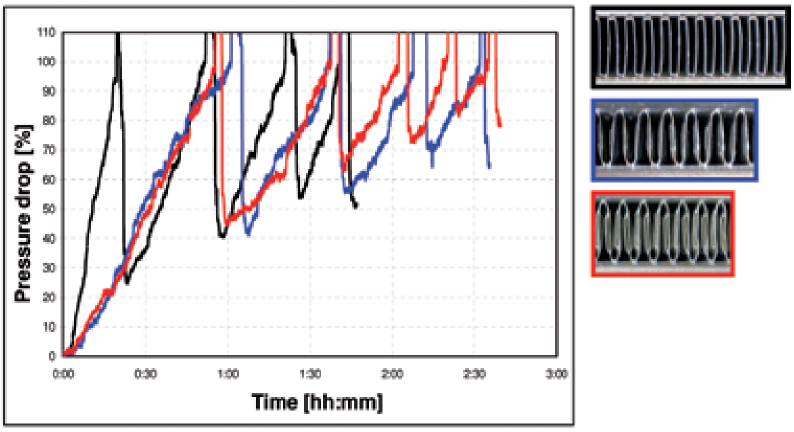

Figure 5: Fouling: Impact of fibers on the pressure loss in coolers and the regeneration of coolers with different fins. Investigations performed by ILK Dresden on behalf of Behr Industry

Figure 6: Solutions designed to prevent fouling – cooling module for city bus featuring swing-out device (top); tractor cooling module with coolers arranged in parallel on the cooling air side (bottom)

radiators themselves, but also complete ready-to-install cooling systems including the radiator/coolers, fan, fan drive, frame, and, if required, also the surge tank, water and oil pumps, and level controller, working in close collaboration with and for its customers.

When solving these technological problems, Behr Industry calls on Behr's development methods, results and products, as they are described in the article "Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles". Behr Industry uses this technology and adapts it to suit the respective engines and the needs of the different special markets. Indirect charge air cooling is standard in commercial vehicle engines. The corresponding indirect charge air coolers are designed in a stacked plate construction. Behr Industry adapts the coolers for a potentially higher engine power. This can be achieved with a simple scaling, that means an increase in the quantity of stacked plates, for example, or, alternatively, by means of bundling existing EGR coolers when there are very high quantities of exhaust gas in the cooled exhaust gas recirculation, for example.

Because the installation position of the engines in special-purpose vehicles is often different from that of conventional commercial vehicles, adapting the components for the new installation position represents another challenge.

If the installation position changes, very often the air ducting on the cooling module or the position of the surge tank relative to the radiator changes as well. In conventional applications, the cooling air is routed from the front through the radiator into the engine compartment. In railway vehicle applications, for example, this is often not possible, owing to the installation position. In roof units, the air is conveyed laterally through the radiator and leaves the module at the top. In other locomotive applications, the radiators are located at the bottom of the module and the cooling air is routed through the assembly from the top to the bottom. If the surge tank for the cooling medium cannot be mounted above the radiator, technical solutions such as an anti-cavitation tank or two-chamber system must be found in order to ensure that the cooling circuit remains free of air. ■

In recent years Behr has made such progress in developing cooled exhaust gas recirculation and iCAC systems that commercial vehicle manufacturers now have at their disposal reliable, production-ready solutions for reducing NO_x emissions. When used in combination, these new cooling systems can meet Euro 5 emissions requirements without the need for a special exhaust treatment process such as selective catalytic reduction (SCR).

Engine Cooling Systems and Cooling Components for Euro 5 Commercial Vehicles

The Author

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1 Introduction

And in contrast to SCR, these innovations do not require any additional operating agent. When they are used in conjunction with the latest engine and injection technology there is no increase in fuel consumption, and they also allow weight reductions at comparable costs. Further benefits are the flexibility of application of these new solutions, and their high potential for further development to meet Euro 6 requirements.

2 Emissions Standards and Reduction Technologies

2.1 Emissions Standards

Since 1992 (Euro 1), the limits for heavy trucks have been brought down in five stages, including some very drastic reductions. Since 2000 (Euro 3) emission limits for NO_x have been reduced from 5 to 2 g/kWh, and particulate emissions from 0.10 to 0.02 g/kWh. In percentage terms this corresponds to a 60 % reduction for NO_x and 80 % for particulates.

2.2 Exhaust Air Cooling and Charging

The exhaust gas recirculation process is essentially based on the fact that the exhaust gas has a higher heat capacity and a lower oxygen content than air. This causes the combustion temperatures in the cylinder to fall. The cooling of the exhaust gas and the charge air makes the temperatures drop even further. Because NO_x formation is an exponential function of these temperatures, a combination of cooled exhaust gas recirculation and turbocharging with CAC was able to meet the Euro 4 limits. Compliance with the stricter requirements of Euro 5 requires either an increase in EGR rates or a reduction in exhaust gas and charge air temperatures. The single stage EGR with two stage turbocharging plus intercooling, and two stage cooled EGR with single stage turbocharging are available for this purpose.

3 Engine Cooling Systems for Euro 5

Over the last few years Behr has been investigating how the increasingly stringent limits can be met by improving engine cooling. In particular, efficient charge air and exhaust gas cooling have a positive effect both on NO_x formation in the combustion chamber and fuel consumption. The newly developed production-ready engine cooling systems for Euro 5 and their components are described below, including comparisons with the SCR system.

3.1 Engine Cooling System with Single Stage Exhaust Gas Cooling and Two Stage Turbocharging

Figure 1 is a functional schematic of such a cooling system. It comprises an exhaust gas cooler which is cooled by the engine coolant, and a low temperature (LT) cooling circuit which contains two charge air coolers and a low-temperature radiator. Since the LT-radiator has a large frontal area and is the first cooler to be exposed to the cooling air flow, very low charge air temperatures can be obtained. This type of CAC is called indirect CAC.

In the EGR cooler, **Figure 2**, the exhaust flow component for recirculation, removed from the engine at the exhaust manifold, is cooled and then added to the charge air upstream of the intake manifold. This causes the temperature of all the intake air to be lowered, which reduces the production of NO_x. However, single stage EGR cooling as used for Euro 4 is not sufficient for Euro 5; this requires either more intensive cooling or an increased EGR rate. For the latter, in order to provide a sufficient oxygen concentration in the cylinder, it is necessary to have a higher charge pressure, which in this system is obtained using two stage turbocharging with intercooling. Two stage turbocharging enables a constant engine output to be maintained in spite of increased EGR rates, and prevents any increase in particulate emissions.

In both charge air coolers the charge air, which undergoes intense heating in each of the two compression stages, is cooled back down and some of the heat which was absorbed is transferred to the liquid coolant. In the LT-radiator this heat is then dissipated into the ambient air. This radiator is installed in the vehicle frontend, which in today's truck diesel engines is the normal location for the conventional charge air cooler, connected to the turbocharger and to the intake manifold of the engine via bulky air ducts. These ducts can be eliminated with indirect CAC, which saves space and simplifies packaging.

The indirect charge air cooler can have a very compact design thanks to its high level of efficiency (compared to a charge air-to-air cooler), and this makes it possible to place the cooler between the turbocharger and the intake manifold. This also means that the charge air ducts do not need to be diverted. The charge air pressure loss can thus be reduced by up to 50 % and the charging pressure can be increased accordingly, which both improves cylinder air filling and simplifies the gas exchange process. Both factors reduce the fuel consumption at a given output.

Dispensing with the air ducts also reduces the air volume in the system. In a 12-l diesel engine a reduction of the air volume of more than 50 % was achieved thanks to iCAC. As a result the system reacts more quickly to load changes. Unlike the situation in passenger cars, however, in commercial vehicles it is not a matter of rapidly increasing torque, but of preventing emissions, for example particulate emissions. The well-known cloud which a truck without a particulate filter produces when the driver suddenly accelerates, happens because the turbocharger cannot supply the amount of air required for full-load operation straight away. There is then not enough oxygen for full combustion of the fuel, and particulate formation briefly increases rapidly. The smaller air volume thus reduces particulate emissions into the environment or the charge build-up on the particulate filter.

The intercooling of the charge air has a positive effect on the efficiency of the second charger. The charging pressure, which today involves pressures of up to 3.6 bar in the case of single stage turbocharging, can reach values of 4 to 5 bar absolute with two stage turbocharging and intercooling. As already described,

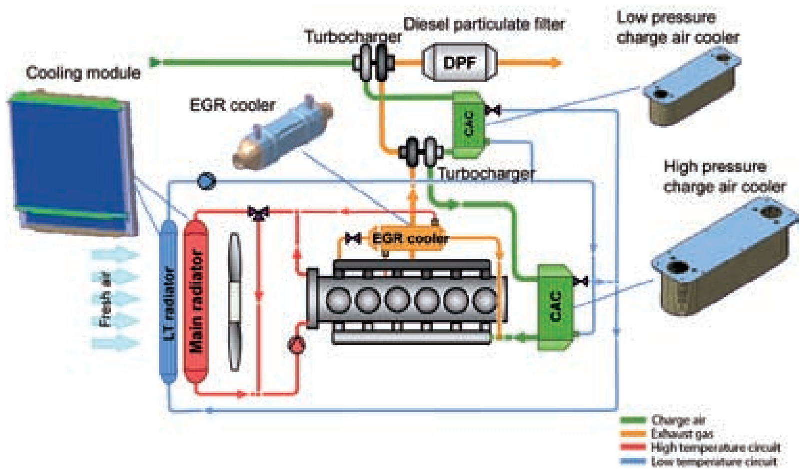


Figure 1: Engine cooling system with single stage EGR cooling and two stage turbocharging

this makes it possible to increase the EGR rates without reducing performance or increasing particulate emissions. Furthermore, a higher charging pressure theoretically opens up the following optimization opportunities:

- Increase in the power density (power per unit of displacement) of the engine. This leads either to increased engine output for the same displacement or smaller displacement for the same engine output ("downsizing"). The latter in particular has a positive effect on fuel consumption due to reduced friction in the engine.
- Increase in the excess air in the cylinder. Owing to the higher oxygen concentration in the cylinder this has a positive effect on soot formation. In other words the fuel is almost completely burned up, and less particulate matter is produced.

3.2 Engine Cooling System with Two Stage Exhaust Gas Cooling and Single Stage Turbocharging

In this system, **Figure 3**, the exhaust gas to be recirculated is first fed to an exhaust gas cooler which is cooled by the engine coolant. It is then routed to a second cooler which, as shown in the functional diagram, is located next to the charge air cooler. In this cooler the exhaust air is cooled by the ambient air. The air flow required for this is produced by the fan and/or by the airflow past the vehicle, according to the travelling speed.

Since the exhaust air is cooled in two stages in this system, resulting in lower exhaust gas temperatures, single stage turbocharging with CAC is sufficient to meet Euro 5 requirements. The charge air is cooled by the ambient air as in a conventional charge air cooler. This is why it is installed at the front of the vehicle where the ambient air flows through it. In this cooling system the exhaust gas and charge air can be brought to approximately the same temperature levels, which significantly lowers the mixing temperature upstream of the Intake manifold. In contrast to the shown separate arrangement of the charge air cooler and exhaust air cooler, this is an integrated cooler, that means a single unit comprising the charge air cooler and the exhaust air cooler.

4 Product Innovations

4.1 Integrated Exhaust Gas Cooler and Charge Air Cooler

The system consists of series-connected individual exhaust gas coolers, **Figure 4**, operating with different cooling media: engine coolant and ambient air. The air-cooled EGR cooler is integrated into the charge air cooler. This form of integration is the first of its kind worldwide.

The exhaust air cooling process: the exhaust gas flows from the cylinders are brought together in the exhaust manifold. From there some of the exhaust flows into the exhaust gas (top right, Figure 4). In this first stage of exhaust gas cooling the exhaust gas is cooled by the engine coolant. This part of the exhaust flow is then conveyed to the second stage, the air-cooled EGR cooler, integrated into the top area of the charge air cooler. When ambient air temperatures are low, the air-cooled exhaust gas cooler can be circumvented by means of a bypass in order to prevent the cooler from freezing. In both cases the exhaust gas then enters the intake manifold and the individual cylinders. It has first been mixed with the charge air cooled in the charge air cooler, so that the intake air has a uniform composition and temperature, which is important for ensuring the same combustion process in all cylinders.

In the first stage of exhaust gas cooling the exhaust gas temperature is reduced to 200 to 150 °C. In the second stage, the low temperature stage, it is then reduced to 25 to 20 K above the ambient air temperature. This lowers the temperature of the intake air overall, based on the mix ratio of charge air and exhaust gas.

The core of the air-cooled EGR cooler consists of tubes conveying exhaust gas and corrugated fins lying between them. In this cooler too, the tubes have been stamped inside to form turbulence-generating winglets.

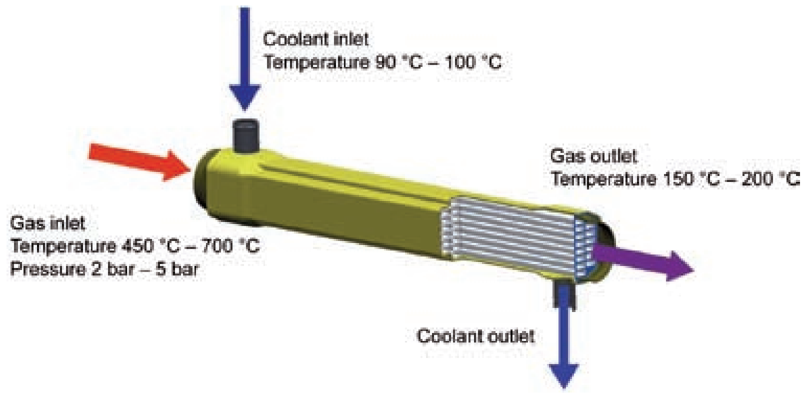


Figure 2: EGR cooler

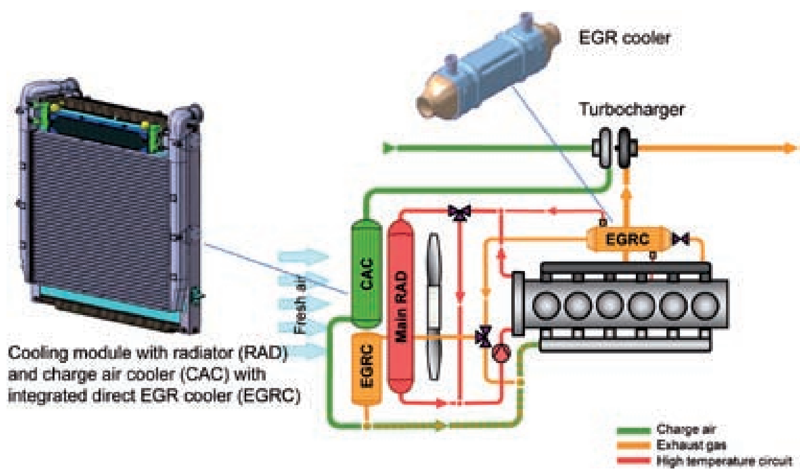


Figure 3: Engine cooling system with two stage EGR cooling and single stage turbocharging

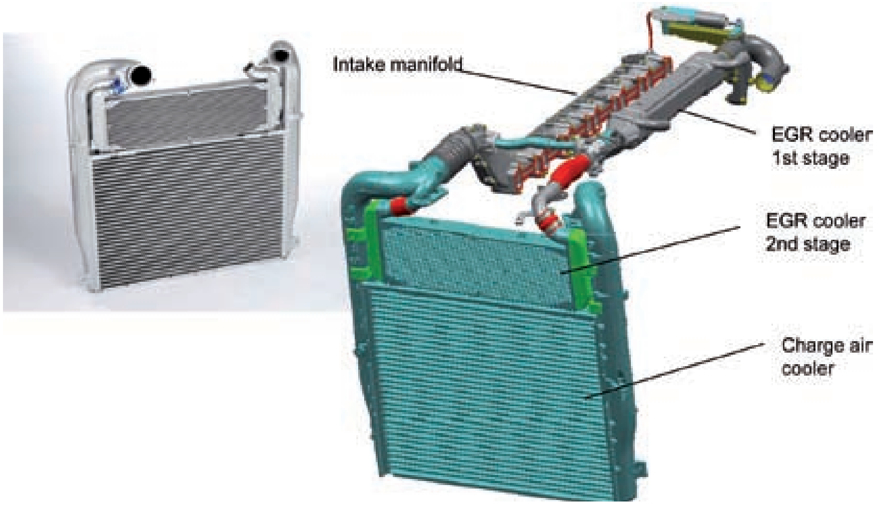


Figure 4: Two-stage EGR cooling: 1st stage coolant cooling, 2nd stage air cooling. EGR cooler integrated in charge air cooler

Figure 5: NFX 750 fan with ERS 250 fan drive

The tubes and corrugated fins are bonded together in a brazing process whereas the pipes and exhaust gas tanks are welded. The cooler consists of corrosion-resistant stainless steel tubes and corrugated fins and the exhaust gas tanks are also made of stainless steel. Features of the integrated charge air/exhaust air cooler module:

- optimized loss of pressure in exhaust gas and charge air cooler
- good mixing of charge air and exhaust gas at the mixing point
- bypass prevents freezing of the exhaust gas cooler
- no return flow of condensate into the charge air cooler
- EGR cooler is corrosion resistant.

4.2 iCAC with Integrated Thermostat

The higher EGR rates for Euro 5 compared to Euro 4 also necessitate higher charging pressures, leading to an increase in the charge air temperature. The charge air coolers used must therefore be able to withstand temperatures of more than 220 °C and pressures up to 5.1 bar absolute. Changes to the design of the charge air cooler can reduce the level of stress, which is based on the pressure and temperature load, to such an extent that the coolers are able to withstand the higher loads.

This aspect was taken into account from the outset for development work on the indirect charge air coolers and, as in the case of the charge air/EGR cooler module, development results were checked with stress analyses using the finite element method (FEM). The indirect charge air cooler is a stacked plate system comprising plates for the charge air and the cooling water ducts. Between the plates there are turbulators for the charge air and the coolant, which are optimized for heat transfer and temperature and pressure requirements.

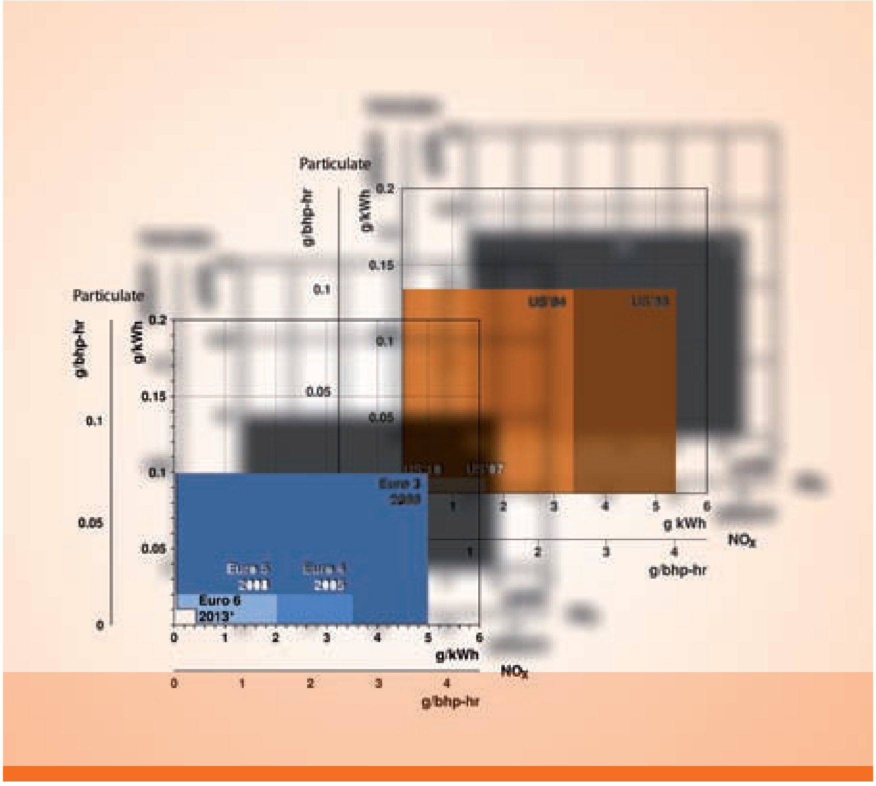
The charge air cooler is operated in a counterflow arrangement, that means the hot charge air flows in on one side and is cooled with cooling water flowing in the opposite direction. It was decided to use two intake ducts for coolant distribution. The coolant flow rate is controlled by means of temperature-controlled choke thermostats at the coolant outlet of the charge air cooler. According to the heat input from the hot charge air, the coolant flow rate is very quickly adjusted by means of fast-responding wax elements, thus avoiding the need for a complex control system.

4.3 Fan and Fan Drive

Fan output has been improved with the new NFX 750 fan, **Figure 5**. The modified blade geometry and higher number of blades (increased from eight to eleven) has boosted fan output while retaining almost the same axial construction depth as in the current series-produced model. The higher fan efficiency has also allowed the drive power to be reduced by approximately 10 % for the same mass air flow. The fan is driven by the Visco ERS 250 fan clutch. This electronically controllable clutch can transfer 40 % more torque than currently used fan drives with comparable size, along with significant improvements in controllability and dynamic clutch response. This means even more precise fan activation than before in response to the actual cooling demand, allowing the complete elimination of superfluous fan noise.

In order to cool the Visco fan drive sufficiently to accommodate its high operating range, the fan hub design has been optimally adapted to the clutch. Flow dividers and flow stabilizers in the region of the fan hub ensure that the inflowing cool air is conveyed through the cooling fins of the clutch and can then flow unobstructed through the fan blades. The result is improved cooling of the silicone fluid in the clutch and a higher slip power tolerance. Another effective means of protecting the silicone fluid in the clutch from overheating is continuous simulation of the silicone fluid temperature in the engine control unit. ■

The NO_x and particulate matter emission limits at Euro 5 and US 2007 (abbreviated as US '07) for commercial vehicle engines are a major challenge for engine and exhaust gas aftertreatment technology. US '07 is already in effect; Euro 5 will come into force in October 2008. Even more demanding technological challenges are to come: from January 2010, US 2010 (US '10) limits will apply in the USA, and the introduction of Euro 6 is expected in 2013. However, the commercial vehicle engines, which will have to meet those limits are being designed now. Behr's low temperature exhaust gas recirculation provides an appropriate technology for these engines.



NO_x Reduction Potential of Cooled Exhaust Gas Recirculation in Euro 6 Commercial Vehicles

The Author

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1 NO_x and Particulate Limits

The **Table** (top) shows how far the limits have reduced from Euro 3. The Euro 6 values are still to be finalized but will involve drastic reductions: in the case of nitrogen oxides (NO_x) probably by more than 80 % (from 2.0 to 0.4 to 0.7 g/kWh) and for particulate matters (PM) by more than 50 % (from 0.02 to less than 0.01 g/kWh). In the USA the forthcoming US '10 limits for NO_x are 0.20 g/bhph (approximately 0.27 g/kWh) and for PM 0.01 g/bhph (approximately 0.0134 g/kWh), Table (bottom). Of course the new limits should be met with the minimum fuel consumption penalty.

2 From Euro 5 to Euro 6

A very important step towards reducing NO_x and particulates in recent years has been the further development of the combustion system. Optimized combustion chambers, improved fuel injection

and turbocharging with charge air cooling meant that it was possible for commercial vehicle engines to comply with the Euro 3 NO_x limits without any special exhaust gas aftertreatment. However, by the time Euro 4 came into being these techniques were, for the most part, no longer sufficient. To meet the new standards additional measures were required.

In terms of internal engine measures, however, it is not possible to minimize both NO_x and PM emissions at the same time (the NO_x/PM trade-off). A viable method of achieving this goal is to minimize one component inside the engine, for example NO_x, and the other outside the engine: in this case the particulates, using a particulate filer. Conversely, reducing particulates by measures inside the engine means that NO_x reduction has to take place downstream of the engine, for example by means of the process of selective catalytic reduction, SCR.

Behr worked together with engineering consultant AVL to investigate the NO_x reduction potential of SCR and cooled exhaust gas recirculation (EGR) technology. The findings indicate that both SCR and cooled EGR are viable options for Euro 5, **Figure 1**.

Euro 6 will require enhancements to the Euro 5 technology, as illustrated in **Figure 2**. Possible concepts are:

- SCR: Selective catalytic reduction, normally combined with single stage charge air cooling.
- EGR: Cooled exhaust gas recirculation combined with two stage turbocharging with intercooling. The exhaust gas cooling also takes place in two stages: a 1st stage of high temperature exhaust gas cooling (HT-EGR), and a 2nd stage of low temperature exhaust gas cooling (LT-EGR).
- SCR plus EGR: combinations of SCR technology and cooled exhaust gas recirculation are also possible. Boosting takes place in a single stage and exhaust gas cooling is a two stage process with high and low temperature stages (HT and LT stages). Other combinations are also possible. However, the common feature in all of these is that they are complex, expensive and require considerable space.

All systems require a diesel particulate filter (DPF) to reduce PM emissions.

3 Selective Catalytic Reduction

The SCR technology already used in Euro 4 and Euro 5 systems for commercial vehicles is based on the addition of urea in the form of an aqueous solution (Adblue) to the exhaust gas flow. Hydrolysis of the urea produces ammonia, a NO_x reducing agent which converts the NO_x into steam and nitrogen in a special catalytic converter. The complete exhaust gas aftertreatment system in this case consists of a diesel oxidation catalytic converter (DOC), a DPF, a hydrolysis catalytic converter (HC), a SCR catalytic converter (SCR cat) and trap catalytic converter (TC), and the Adblue tank and a metering unit.

However, the extremely low Euro 6 and US '10 limits probably cannot be met with catalytic NO_x reduction alone. This is because of the new test cycles for measuring the emissions. Instead of the ETC (European Transient Cycle) currently specified, for Euro 6 it is likely that the new WHTC (World Harmonized Transient Cycle) will be used. This cycle results in lower engine speed and load overall and, therefore, lower exhaust gas temperatures.

However, low exhaust gas temperatures reduce the generation of ammonia from the urea solution. Additionally, at low temperatures the catalytic converter also loses some of its efficiency. Thus the

Table: NO_x and particulate emission limits for heavy duty trucks (> 3.5 t) for Europe (top) and the USA (bottom)

Phase	Introduction date	NO_x [g/kWh]	Particulate [g/kWh]	Test cycle
Euro 3	October 2000	5.0	0.10 (0.16)	ESC (ETC), ELR
Euro 4	October 2005	3.5	0.02 (0.03)	ESC (ETC), ELR
Euro 5	October 2008	2.0	0.02 (0.03)	ESC (ETC), ELR
Euro 6*	2013	0.4 – 0.7	0.01	WHTC, WHSC

ESC: European Steady State Cycle
ETC: European Transient Cycle
WHSC: World Harmonized Steady State Cycle
ELR: European Load Response Test
WHTC: World Harmonized Transient Cycle
Values in parenthesis: ETC
Introduction date for new type approvals; for all type approvals normally one year later
Limit values for CO and HC not shown here
* Euro 6 not defined specifically, decision expected in 2008

Phase	Introduction date	NMHC + NO_x [g/bhp-hr]	NO_x [g/bhp-hr]	Particulate [g/bhp-hr]	Test cycle
US'98	January 1998	-	4.0 (5.36)	0.10 (0.134)	HD-FTP
US'04	January 2004	2.5 (3.35)	-	0.10 (0.134)	HD-FTP, SET
US'07	January 2007	-	1.2 (1.61)	0.01 (0.0134)	HD-FTP, SET
US'10	January 2010	-	0.2 (0.27)	0.01 (0.0134)	HD-FTP, SET

HD-FTP: Heavy Duty Federal Test Procedure
SET: Supplemental Emission Test
Values in parenthesis: g/kWh (conversion factor: 1 g/bhp-hr = 1.34 g/kWh)
Limit values for CO and HC not shown here

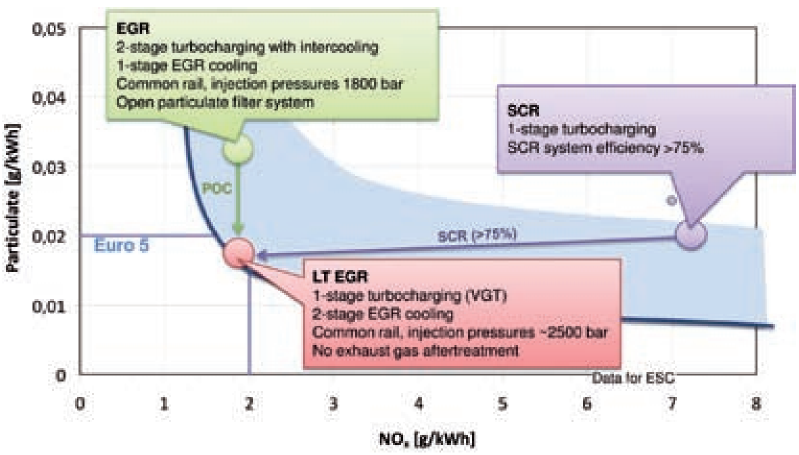

Figure 1: Technologies for Euro 5 – state of the art for the NO_x/PM trade-off

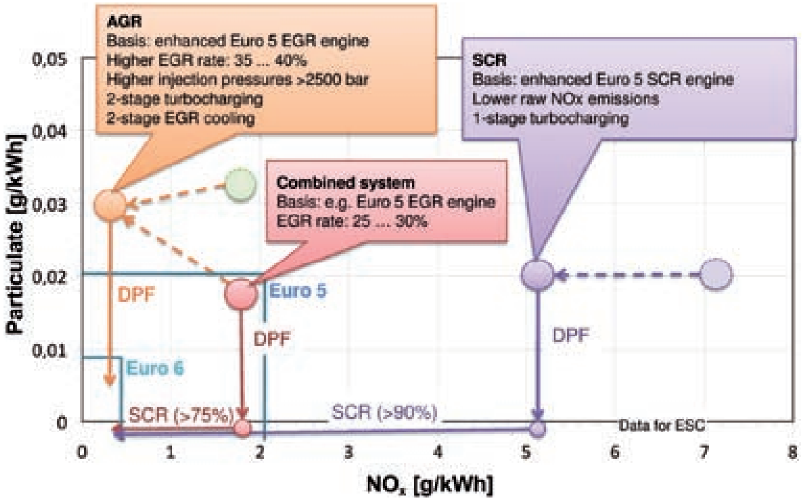

Figure 2: Technologies for Euro 6 – enhancements based on Euro 5

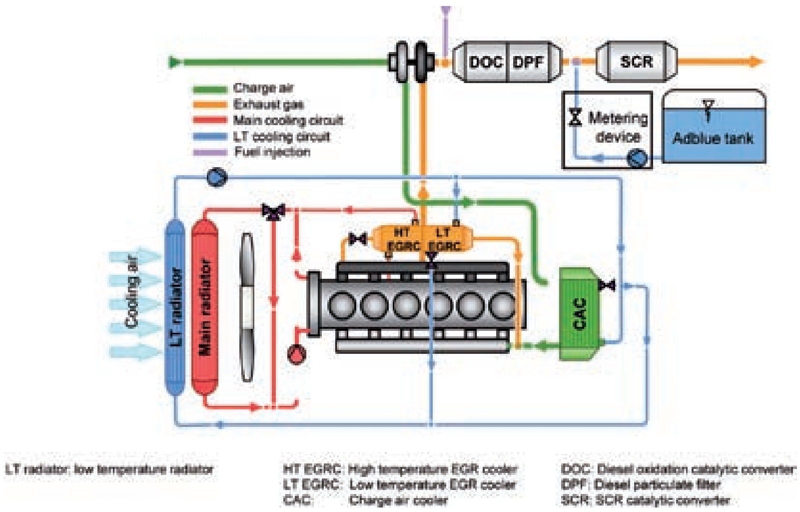

Figure 3: Combined system for Euro 6: EGR and SCR

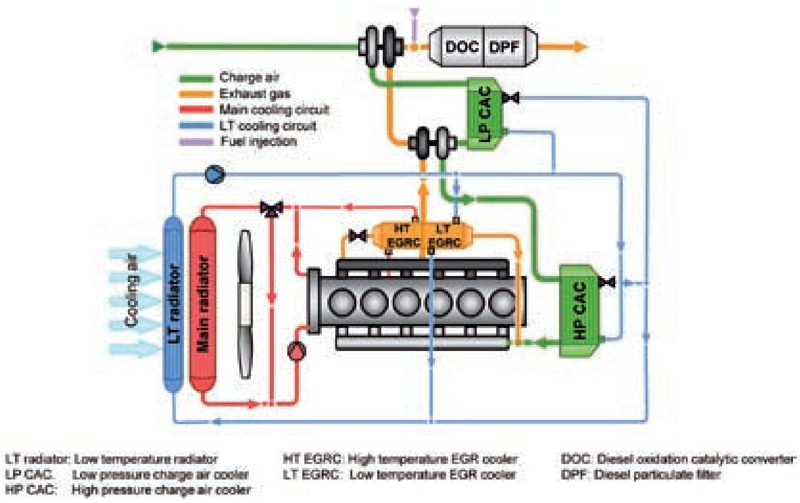

Figure 4: Potential two-stage EGR system for Euro 6

NO_x conversion rate is limited in two ways. In addition, the WHTC includes a cold test which further reduces the rate of conversion in the first part of the cycle. The resulting increase in NO_x emissions probably cannot be offset in the second hot parts of the test.

The transition from Euro 5 to Euro 6 requires an 80 % reduction in NO_x emissions. If this objective is to be achieved with selective catalytic reduction alone, the efficiency of the technology will have to be significantly increased, from around 75 % today to more than 90 %. That is not all: to offset the temperature effect from the new test cycles as described above it will be necessary to further boost the efficiency of the SCR system. Accordingly, it may be difficult to meet Euro 6 and US '10 using SCR alone.

One possible method for achieving the Euro 6 legislation would be to combine SCR and EGR technology, **Figure 3**. Since cooled EGR means less NO_x is produced in the engine, there is also less NO_x to be converted by catalytic reduction in the exhaust system. The drawback of this combined system, as mentioned previously, is its size and complexity.

4 Exhaust Gas Recirculation with Two Stage Cooling and Two Stage Turbocharging with Intercooling

4.1 Two Stage Exhaust Gas Cooling

Exhaust gas recirculation reduces the oxygen concentration of the cylinder charge, thus reducing the speed and temperature of combustion. Since the rate of NO_x formation is exponentially dependent on the combustion temperature, cooled exhaust gas recirculation is associated with a significant reduction in NO_x emissions. Cooling the exhaust gas also improves cylinder filling and reduces thermal stress on the engine components.

With cooled exhaust gas recirculation, some of the exhaust gas is diverted upstream from the turbocharger turbine and routed to the exhaust gas cooler via an EGR valve. In the case of two stage cooling, **Figure 4**, the first cooling stage is high temperature cooling (HT EGRC), the cooling medium is the coolant from the main cooling circuit, and in the second cooling stage (low temperature stage,

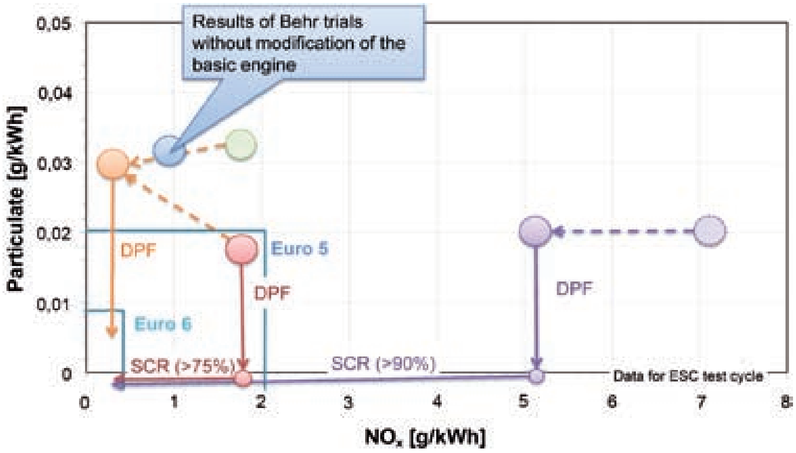

Figure 5: Potential of LT-EGR with respect to Euro 6

LT EGRC), it is the coolant from a low temperature circuit. To prevent the coolant from boiling in the first cooling stage, the exhaust gas and coolant flow in the same direction; the second stage operates in counterflow mode, which improves the cooling performance.

4.1.1 Self Cleaning of the EGR Cooler

A major advantage of two stage exhaust gas cooling – as compared with single stage cooling – is the self cleaning action of the EGR cooler and thus the stabilization of its cooling performance over the life of the cooler. This cleaning action is a consequence of the formation of condensation in the exhaust gas cooler. During the combustion, 1.26 kg of water for every 1 kg of diesel fuel is produced. Some of this steam condenses in the EGR cooler, where the condensation washes the deposits off the tubes of the cooler.

4.1.2 Cooling by Evaporation

Along with this self cleaning action, exhaust gas condensation also reduces the in-cylinder temperatures: firstly by the cooling effect from the evaporation of the charge air exhaust gas mixture and secondly by cooling due to evaporation of the intake air in the cylinder.

Cooling due to evaporation occurs when the condensate in the exhaust gas mixes with the dry charge air and evaporates. The heat required for this to happen comes from the charge air exhaust gas mixture, resulting in a fall in temperature of approximately 10 K. Because of the high dew point of steam, this cooling action occurs at high temperatures, for example 40 to 60 °C.

The exhaust gas condensate evaporates in the intake air but not completely: some water is remains and is conveyed with the intake air into the cylinders, where it evaporates in the compression phase. This second cooling effect limits the increase in the charge temperature during compression, lowering combustion temperatures and, therefore, NO_x emissions.

4.2 Two Stage Turbocharging with Intercooling

Cooling the charge air while keeping maximum cylinder pressures unchanged results in higher performance, lower fuel consumption and less formation of NO_x. In the LP and HP charge air coolers, Figure 4, the charge air, after being heated in each of the two compression stages, is cooled. The cooling of the charge air between the compressors, hence the term "intercooling", improves the efficiency of the second compressor.

4.3 Results

In various tests Behr together with AVL has already reduced NO_x values to about 0.8 g/kWh over the test cycle. However, the optimum has still not been reached. It might be possible to reach the Euro 6 limit, which is likely to be in the region of 0.7 to 0.4 g/kWh, **Figure 5**. It should, however, be noted that low temperature EGR is likely to be successful only in combination with two stage turbocharging and advanced fuel injection systems.

5 Conclusions

The Euro 6 and US '10 emissions limits are unlikely to be met using SCR technology alone. Cooled exhaust gas recirculation (EGR) will be part of the emissions solution. A combination of SCR and EGR is possible but may have weight, packaging, complexity and cost penalties.

A possible solution is the two stage cooled exhaust gas recirculation process described above, combined with two stage turbocharging. This system possibly has the potential to achieve the potential Euro 6 limits. It should be noted that cooled EGR will also play a key role in enabling off-highway vehicles meet future emissions limits.

Measurement of Tyre-Road Noise in the Interior of Passenger Cars

In particular with vehicles of the upper middle class and the upper class the acoustic climate in the interior is an important purchase criterion during all operating conditions. The vehicle manufacturers constantly reduced the noise level in the vehicle interior therefore in the last years. Here also the airborne sound, produced in the contact zone between tyre and roadway, must be considered, because it forms the noise impression in the vehicle interior considerably. In this paper an experimental method is presented, with which the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS) can quantitatively determine this noise entry. With the new patented test stand method a contribution is made to an efficient vehicle development process, which makes a total acoustic optimisation possible on test stand conditions. Road tests are reduced. At the same time the well-known disadvantages by acoustic chassis dynamometer test benches are avoided.

1 Introduction

Test stand as well as road measurements carried out at the Research Institute of Automotive Engineering and Vehicle Engines Stuttgart (FKFS) are designed to provide information on how the individual components of engine and drive-train noise, rolling noise (structure-borne sound caused by the wheel suspension), tyre-road noise (air-borne sound from outside the vehicle) and wind noise combine to form the overall interior noise experienced in passenger vehicles under varying background conditions. This has been successfully clarified in the case of some significant components [1]. However, there have not been any clear-cut results to show which operating conditions and frequency ranges cause tyre-road noise to become dominant. As the intensity of tyre-road noise increases with the 3rd to 4th order of vehicle velocity, whereas drive train and rolling noise increase at a mere 2nd to 4th order, it must be assumed that with increasing speed tyre-road noise contributes substantially to interior vehicle noise.

In the past interior tyre-road noise has been measured on roller dynamometers, albeit with this type of measurement structure-borne rolling noise and tyre-road noise cannot be differentiated, and also the noise generation mechanism cannot be simulated adequately owing to roller curvature and dissimilarity between the roller lining and the road surface texture. Moreover, the driving roller‘s intrinsic noise can be a factor interfering with the measurement readings.

For the above reasons the FKFS developed a test stand method which allows simulation of tyre-road noise separately from the other noise sources, without causing disturbing noise components in the process. The objective of this procedure was an overall acoustic vehicle optimisation under test stand conditions including tyre-road noise; avoiding additional measurements on road.

2 Tyre-Road Noise

Tyre-road noise is caused right at the zone of contact of tyre and road. It is then deflected, with part of it penetrating through the vehicle body into the interior of the vehicle. The most crucial causes of tyre-road noise are radial and tangential tread vibrations due to patterns of forces in the contact zone, as well as aerodynamically induced mechanisms such as air displacement in the tread channels (air-pumping). The tonality of the sound is influenced by tread resonances [2], **Figure 1**.

2.1 Measurement of Tyre-road Noise in Close Proximity to the Tyre

In order to determine to what degree tyre-road noise contributes to the noise in the vehicle interior, the sound field of the tyre to be examined is measured in close proximity to the tyre at three different points, using the tyre-noise measurement trailer developed by the FKFS [3]. Vehicle velocity, type of road surface and tyre model are used as parameters. The measuring trailer shown in **Figure 2** is a single-wheel trailer with a sound-absorbent lining. Measurements are carried out including the vehicle-specific wheel housing (wheel-house protector) in order to simulate the actual sound propagation conditions on the vehicle (reflection, absorption) as realistically as possible. Microphones are placed on the trail and lead side as well as on the outward sidewall of the tyre, Figure 2.

2.2 Simulation of Tyre-road noise on a Test Stand

In order to simulate tyre-road noise on a test stand the vehicle is mounted on speaker boxes which contain four speakers, **Figure 3**. One speaker on the lead side of the tyre, one on the trail side and one on the outward and inward wallside respectively, so that the tyre sound field can be imitated as realistically as possible. Simulation of the tyre sound field is carried out individually for each wheel. In a first simulation run the microphone

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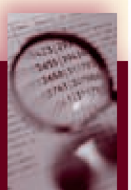

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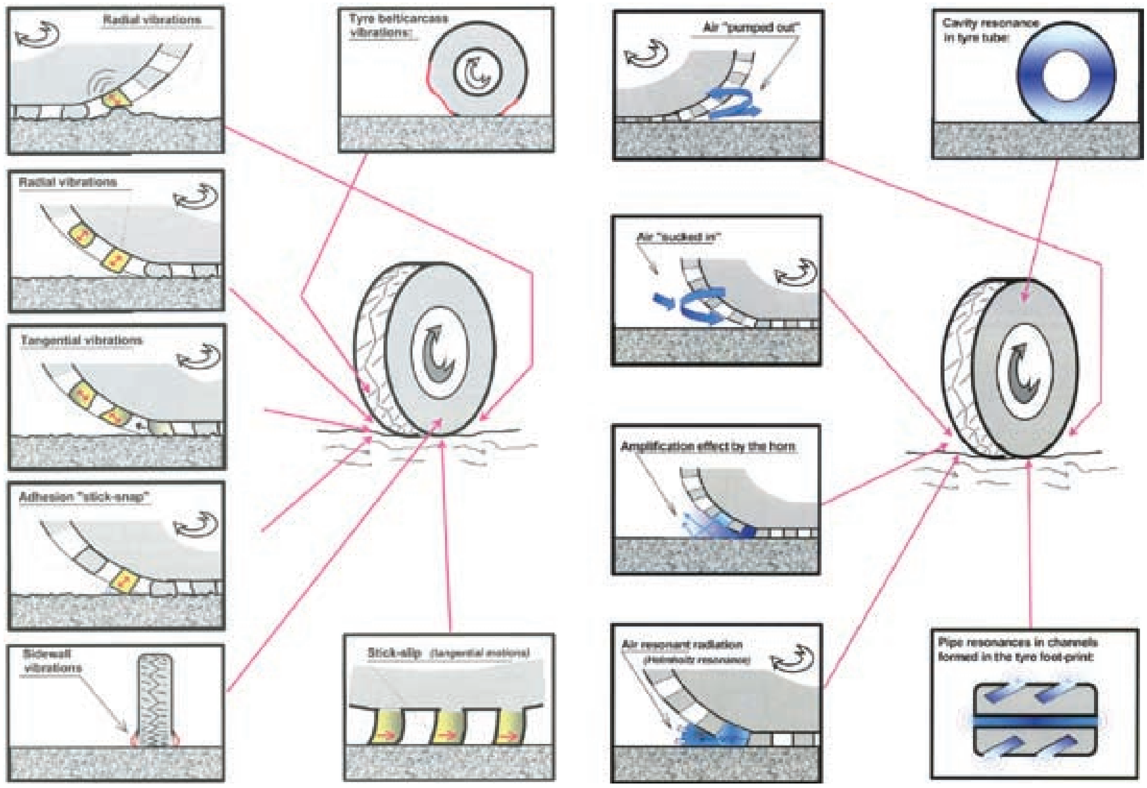

Figure 1: Mechanisms responsible for generation of tyre-road noise [2]

signals recorded on the road are used as input signals for the speakers. Then the sound pressures are recorded with microphones at the same microphone positions as in the road measurements. Subsequently the frequency spectrum is calculated.

The sequence of operations used in the patented method [4] for sound field simulation on a test stand, including use of a sound system and measurement technology, is shown schematically in **Figure 4**. Owing to the reflecting properties of the speakers and the test stand conditions, results differ from those measured on the road. Taking into account the differences in level of the individual microphone signals in relation to one another, these level deviations are used as a filter function for a new loudspeaker input signal. This is done with the help of an equalizer with third-octave spacing. The signal generated in this way is played again over the loudspeakers and is then recorded, analysed and compared with he original road signal. When the original signal and the test stand signal are sufficiently well matched, the iteration loop is closed.

The absolute sound pressure level does not necessarily have to be achieved here, as the difference from the actually occurring sound pressure level can later be corrected mathematically. Setting the sound pressure levels and spectra at the respective microphone positions in relation to each other and in keeping with the road measurement is sufficient. **Figure 5** compares a simulation result with the spectrum obtained in the measuring trailer. It shows the third-octave spectra

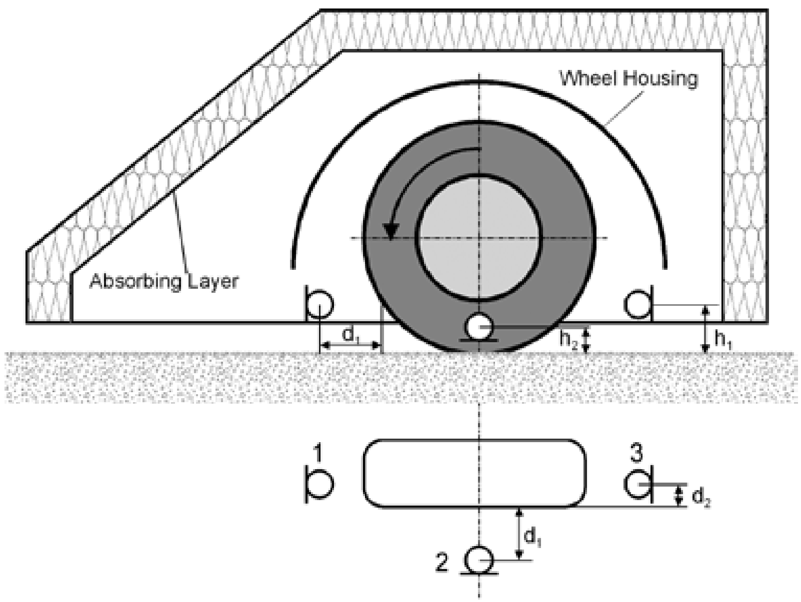

Figure 2: Microphone positions at the FKFS tyre-noise measurement trailer used for measuring the tyre sound field (h_1 = 120 mm, d_1 = 100 mm, h_2 = 70 mm, d_2 = 50 mm)

Figure 3: Speaker box and microphone array in a simulation of tyre-road noise on a test stand

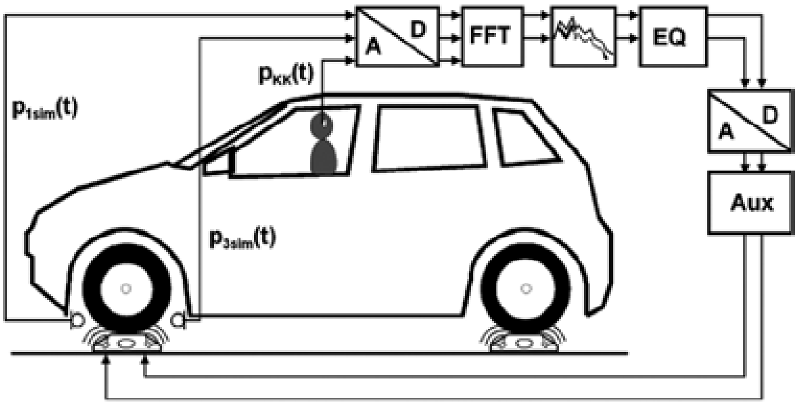

Figure 4: Schematic diagram showing basic set-up and sequence of the simulation process for the determination of tyre-road noise (microphone at the outward sidewall of the tyre is not shown)

recorded by the microphone at the tyre lead while running on an asphalt pavement at 70 km/h. The two signals correlate well over the entire frequency range. A clear deviation between road and test stand signals only shows at levels below the reproduction frequency of the loudspeakers – in this case below approximately 60 Hz.

After carrying out the iteration, the contribution of tyre-road noise to the overall interior noise can now be determined. Assuming that the noise emission of the individual tyres represents uncorrelated noise sources, it is also possible to determine the contributions of the individual tyres to the overall noise in the interior of the vehicle by operating just one loudspeaker box.

3 Results

In the following Influence of road surface texture, vehicle comparison and noise components are described more in detail.

3.1 Influence of Road Surface Texture

The influence of the road surface texture on tyre-road noise in the vehicle interior can be determined with the help of the test stand method described above. A concrete surface causes an increased sound radiation in the lower frequency range, **Figure 6**. Here the frequency range where more noise is radiated on a concrete road depends on the vehicle speed. With increasing vehicle speed this range shifts to higher frequencies.

3.2 Vehicle Comparison

Figure 7 illustrates how different radiation properties of the tyres and vehicle-specific noise damping result in varying levels of interior noise. It shows the tyre-road noise levels in the vehicle interior for two passenger cars of the upper middle class moving at 90 km/h on an asphalt surface. Vehicle B generates higher levels than Vehicle A over the entire frequency range. The degree of noise damping, as well as the tyre-road noise in close proximity to the tyre (not shown), can also be determined by the method described above, thus providing two more parameters with the help of which varying vehicles of different tyre types can be compared with one another.

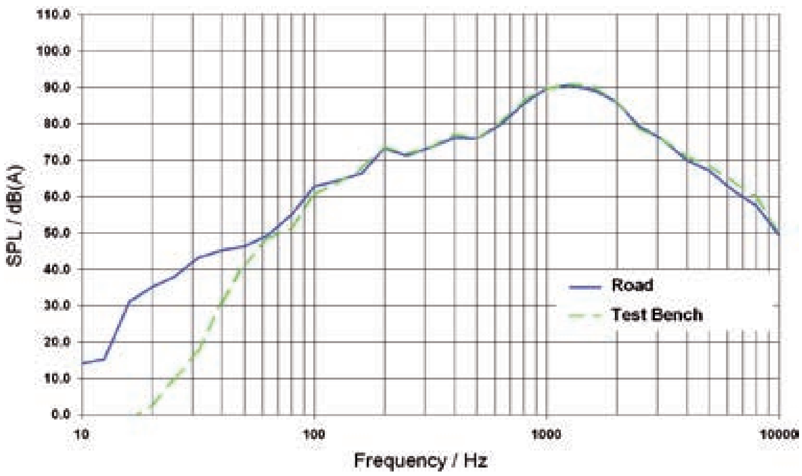

Figure 5: Tyre/road noise, comparison of measurements on road to on test bench; comparison of third-octave spectra of the microphone at the tyre lead between road and test stand measurement (asphalt, 70 km/h)

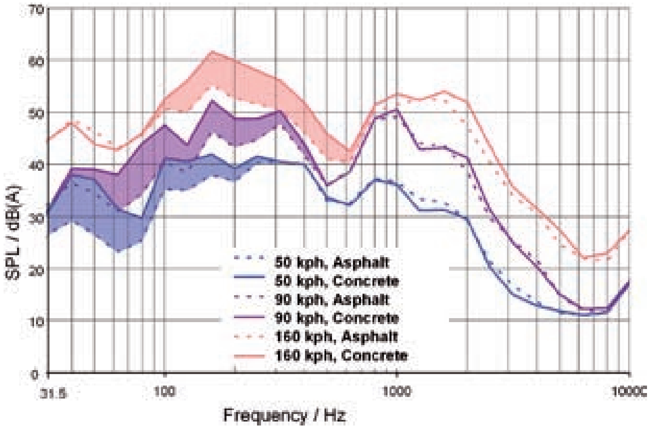

Figure 6: Tyre-road noise in the interior of a vehicle of the upper range of the standard class at three different speeds on an asphalt and a concrete surface

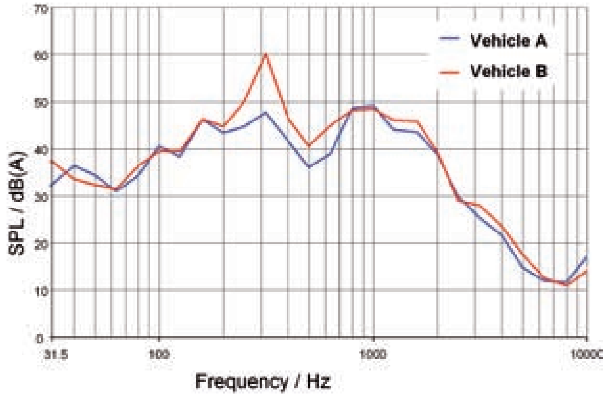

Figure 7: Tyre-road noise in the interior of two vehicles of the upper middle class moving at 90 km/h on an asphalt road

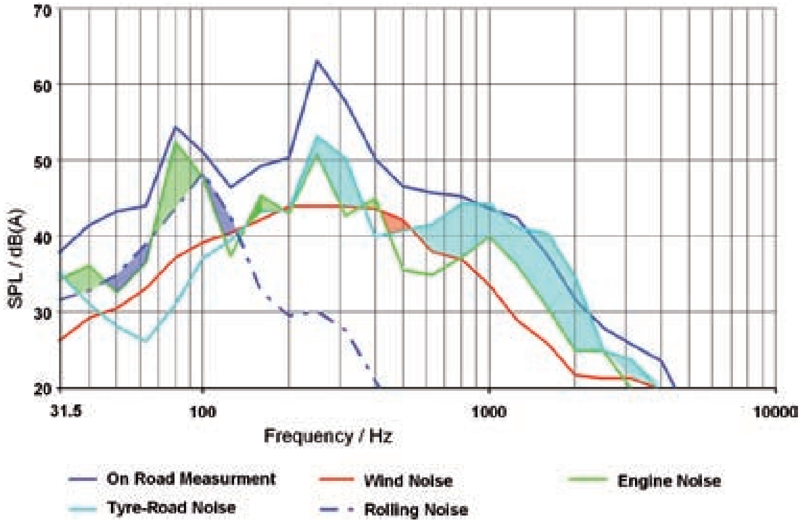

Figure 8: Noise components in the interior of a vehicle of the upper range of the standard class at 70 km/h on an asphalt road

3.3 Noise Components

A comparison of the individual noise sources shows that the noise contribution of the tyre-road combination to the overall noise peaks at 1-2 kHz, and becomes the loudest noise source in this frequency range at 70 km/h, **Figure 8**. In the 250 Hz third octave the tyre-road noise of the vehicle shows a marked peak which points to a tonal noise component of the tyre. This has a decisive effect on the overall noise level.

The wind noise is measured in the full scale vehicle wind tunnel. Engine and drive train noise are recorded separately on another test bench, the FKFS vehicle noise test stand. Engine speed, engine load and transmission ratio are the operating parameters. There are no interfering components of tyre-road noise as the wheels do not turn. Reference [5] explains the set-up of the test stand in more detail. A servo-hydraulic four-piston hydropulse test bench is available at the FKFS for the determination of rolling noise, which can simulate interior noise up to the 125 Hz third octave.

4 Summary

The method described here by FKFS makes it possible to simulate tyre-road noise apart from all other noise components in the vehicle. Its contribution to the overall noise level can thus be determined by measurement. The method can be used for any combination of tyre types and road surfaces at varying driving speeds. Furthermore it is possible to reproduce tyre-road noise in a way true to hearing, so that it can also be subjectively assessed.

This patented test method thus improves the efficiency of vehicle development by permitting an overall acoustic optimisation under test stand conditions, so helping to reduce road tests while at the same time avoiding the known disadvantages of acoustic roller test stands.

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Dr. Akihiko Saito
FISITA President

"FISITA is an Engineering Congress – Not a Lobby Group"

In the run-up to the FISITA World Congress from September 14 to September 19, 2008 in Munich (Germany) ATZ and the outgoing FISITA President Dr. Akihiko Saito, talked about his personal goals, the experiences he has made being President of the world body for automotive engineers and the 32. FISITA World Congress. Also the challenges the automotible industry has to face were discussed by Saito, who is Senior Technical Executive at Toyota as well.

ATZ In your opinion, what is the main function of FISITA?
Saito FISITA's mission is to share knowledge among the world's automotive engineers and by doing so, contribute to the development of automotive technology.

ATZ What would you say are the biggest challenges that the automotive industry has to face nowadays?
Saito Our biggest challenge is to develop a new approach to product development which is more forward-looking and proactive. Toyota's vision for research and development can be summed up in two words: "Zeronise" and "Maximise". "Zeronise" means we are striving for zero negative impacts on our environment, zero accidents and zero traffic congestion. At the same time, we are striving for maximum positive impact on personal enrichment through comfort and fun. This philosophy is key to gaining widespread consumer acceptance of more sustainable technologies. Take as an example Toyota's petrol hybrid vehicle Prius, which gained worldwide popularity when the second generation was launched in 2003. It provides outstanding environmental performance, and at the same time, uplifting driving performance. This is exactly the realisation of both "Zeronise" and "Maximise".

ATZ What are the goals, the expectations for the FISITA World Congress 2008?
Saito Our first goal is always to have excellent quality technical information and lively exchange between engineers from industry and academia. We will also have an innovation at the Munich congress that we are calling "Islands of Excellence". We had a competition in which universities from around the world applied for the chance to present their automotive research projects.

ATZ What impacts will the congress have, politically and on the automotive industry?
Saito We have to keep in mind that FISITA is an engineering congress – not a lobby group. But we know that today, people everywhere are more concerned about the social and environmental impact of the automobile than ever before. Politicians have to react to that concern,

"Our biggest challenge is to develop a new approach to product development which is more forward-looking and proactive" but to do this well, they must understand the facts. I worry that, too often, the message from some of our leaders seems to be "don't worry, technology will come along and solve everything". The present concern over oil prices and future alternatives to fossil fuels is a prime example. As engineers and scientists, we accept that the world is looking to us to find solutions to sustainable mobility. And every day we are making progress. But we are not magicians. We know that sustainable mobility calls for a partnership between players in the automotive industry, but also energy companies, policy makers and consumers. Cleaner, safer vehicles also need better infrastructure, improved urban planning, better driver education and the right fiscal incentives. If we can use the FISITA Congress to help convey the technical reality behind the choices facing governments around the world, then I believe we can contribute to a climate where mobility policy decisions are based on the best scientific knowledge, and not just on short-term political expediency.

"Our first goal is always to have excellent quality technical information and lively exchange between engineers from industry and academia"

ATZ If you look back, with which goals and ambitions did you start as FISITA President?

Saito When I was a young engineer starting my career with Toyota, it was considered a great honour to be asked to present a paper at the FISITA Congress. Today the industry is much more global and the pace of technical development is faster. There are many more competing conferences and sources of information on offer for engineers. So when I had the privilege to be elected FISITA President, my ambition was to strengthen our association so that we can respond more rapidly to the changing needs of our members and protect FISITA's reputation as the world body for automotive engineers.

ATZ What did you achieve, in which concerns do you think you have brought FISITA forward?

Saito We have expanded our links with industry. Today, most of the leading global vehicle manufacturers and top suppliers support FISITA, which is vital to our future development. Just as important is the fact that now, among our FISITA Honorary Committee we also have the three leading energy companies, along with leading companies from the electronics and Intelligent Transportation Systems worlds. This is important for us because we have to build links between engineers working in the vehicle world – our traditional members – and those colleagues working in related and increasingly important areas like fuels and lubricants, electronics and telematics. We have also welcomed our first member companies from India and China – the two fastest-growing automotive economies, where FISITA has to be more involved. In 2012 we will have the FISITA Congress in Beijing, hosted by SAE China. I think we can be proud of the progress we have made in strengthening FISITA's organisation over recent years, but there is still much work to be done.

ATZ Which personal conclusion can you draw from your presidentship?

Saito The activities we support in the education area, such as our sponsorship of the FISITA Formula SAE World Cup, has given me the chance to meet students from around the world as they take part in exciting, highly successful competitions organised by our member societies. This has led me to conclude two things: First, that the work of FISITA and our 38 societies makes a real difference. And second, that the next generation of automotive engineers absolutely possess the skills and the talent needed to solve the challenges we now face.

ATZ Dr. Saito, it has been a pleasure talking to you.

Interview conducted by Roland Schedel.

Dr. Akihiko Saito

is FISITA's President for the 2006 to 2008 term. He was born in 1940 and joined Toyota in 1968 after earning a Doctorate in Mechanical Engineering at Nagoya University (Japan). In 1980, Dr. Saito became a member of the team that handled product planning work for the Corolla, served as Chief Engineer and became a General Manager in the Product Planning Division in 1987. Dr. Saito was named to the Board of Directors in 1991, became Managing Director in 1996 and Senior Managing Director in 1998. In 2001 Dr. Saito assumed the position of Executive Vice President. In July 2005 he became Senior Technical Executive in Toyota and also Vice Chairman of Denso. He was named Chairman of Denso in June 2007.

Dr. Akihiko Saito, FISITA President, Senior Technical Executive Toyota Motor Corporation