Vehicle cooling

A compact guide for the workshop

What is thermal management?

Thermal management includes ensuring the optimal engine temperature in all operating conditions as well as heating and cooling the vehicle cabin. A modern thermal management system therefore consists of engine cooling and air conditioning components. The components in these two assemblies, which interact with each other, often form a unit. This booklet covers modern cooling systems and their technical background. In this context, we also deal with the principles of operation, causes of failure, characteristic features, and diagnostic options.

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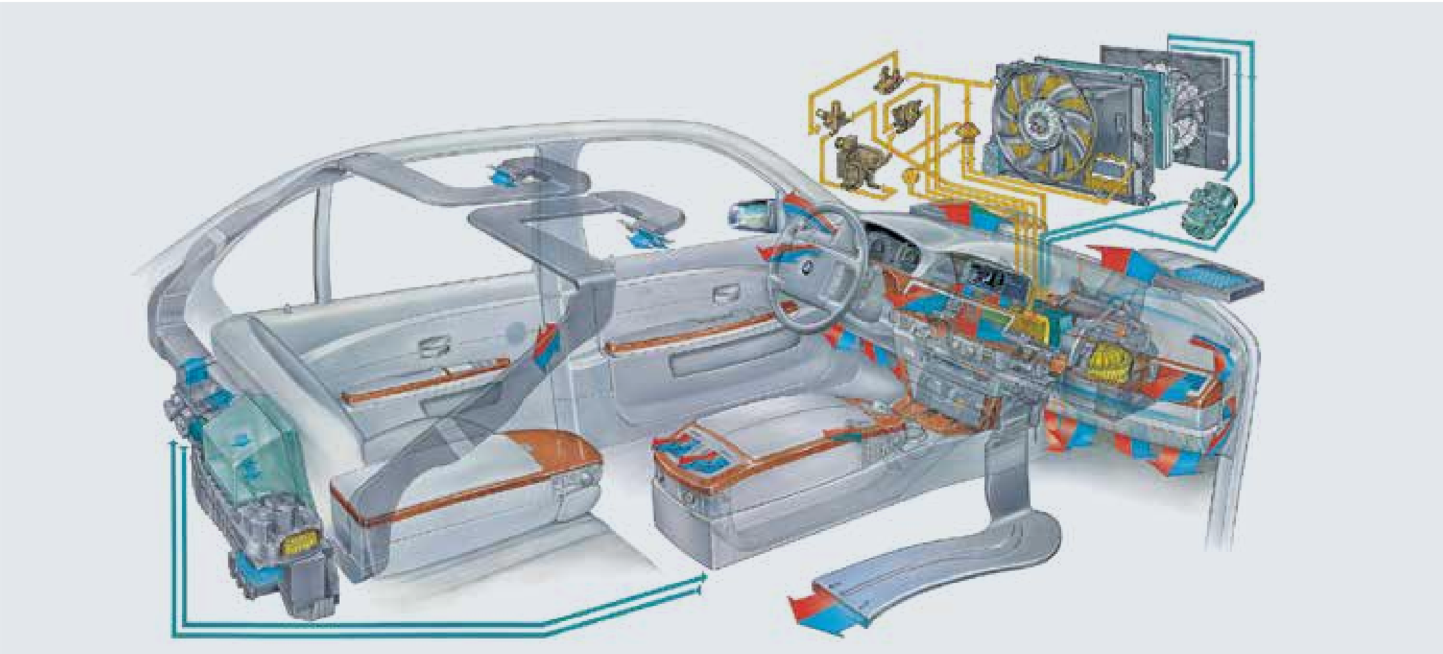
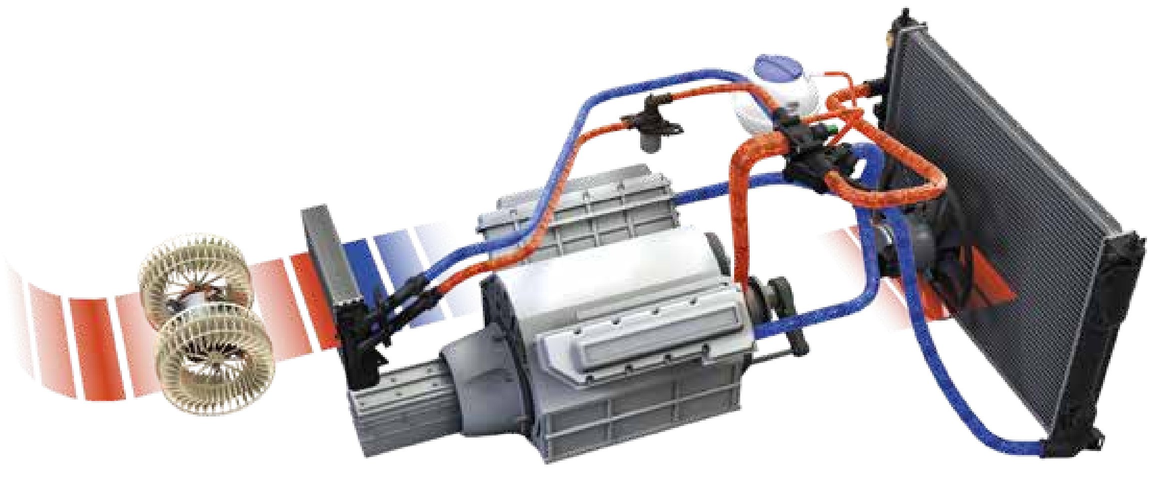
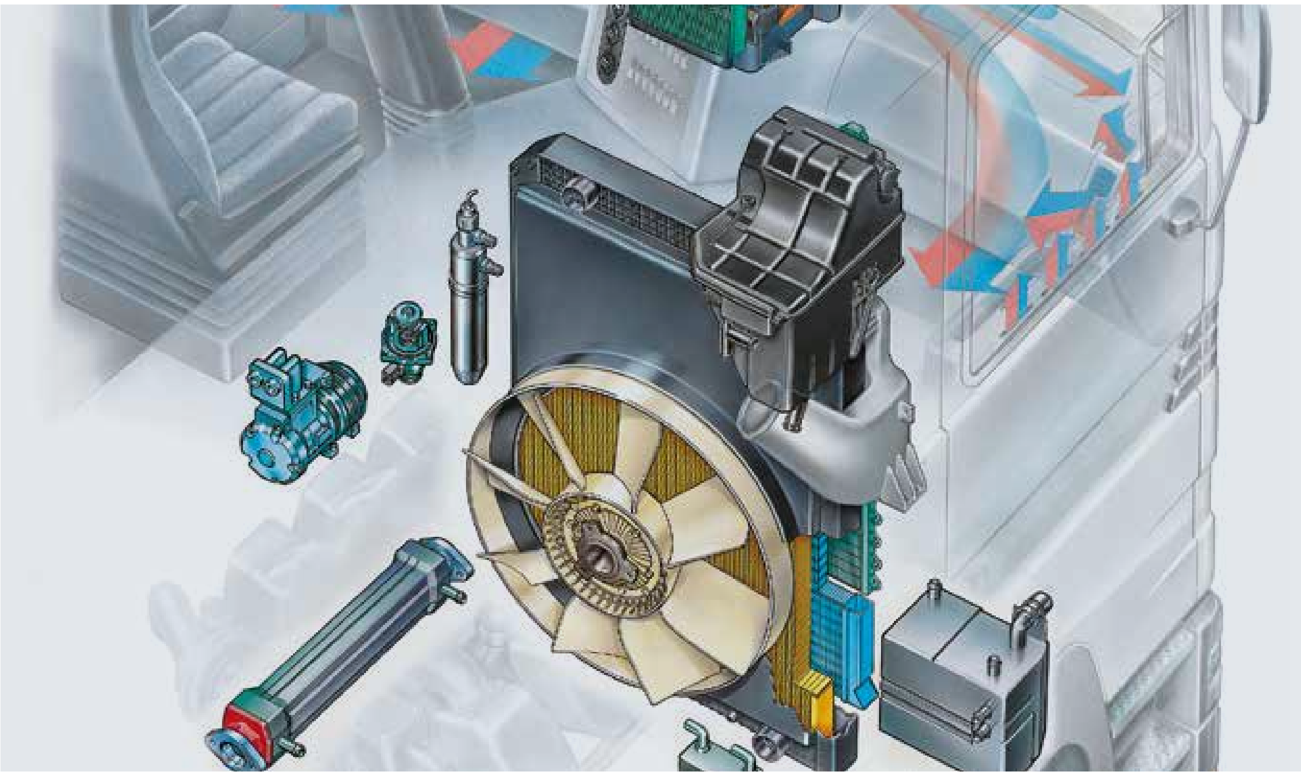
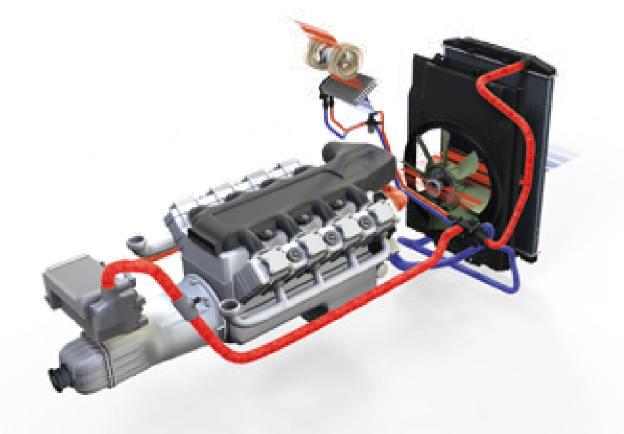


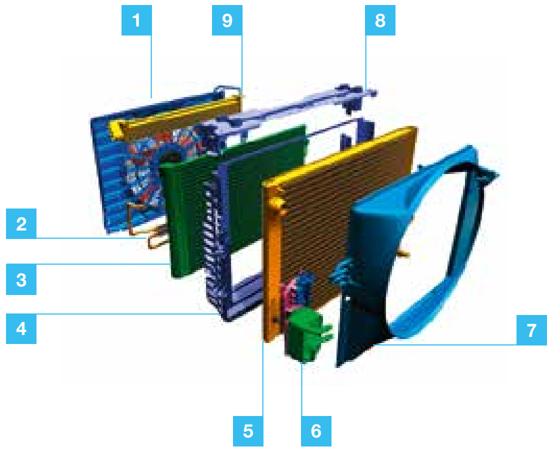
Integrated system—passenger cars

All of the heat generated by an engine and its dependent systems must be dissipated. Today, the operating temperature of an engine is only permitted a small tolerance in order to control operation and ambient temperature (engine and interior). Emissions values can be affected by an increased operating temperature, leading to faulty engine control. In addition, in engine variants such as direct injection, both diesel and gasoline, which generate only a small amount of heat, the cooling system must warm the vehicle occupants in winter and cool them in summer. All these factors must be considered when developing a thermal management system. Added to this is the requirement for higher performance and efficiency in a smaller installation space.









Integrated system—commercial vehicles

This is a typical example of the current status of thermal management in commercial vehicles. We will look at both segments—passenger cars and commercial vehicles—below.

Design of a modern cooling module

This is a typical example of the current status of a cooling module. It consists of the radiator, engine oil cooler, air conditioning condenser, transmission oil cooler, power steering cooler, and radiator/air conditioning condenser fan.

1 Pressure shroud with electrically driven fan

2 Power steering cooler

3 Air conditioning condenser module

4 Module frame

5 All-aluminum radiator

6 Transmission oil cooling

7 Suction shroud for engine fans

8 Module frame cover

9 Engine oil cooler

Cooling: a retrospective view

Engine cooling with water

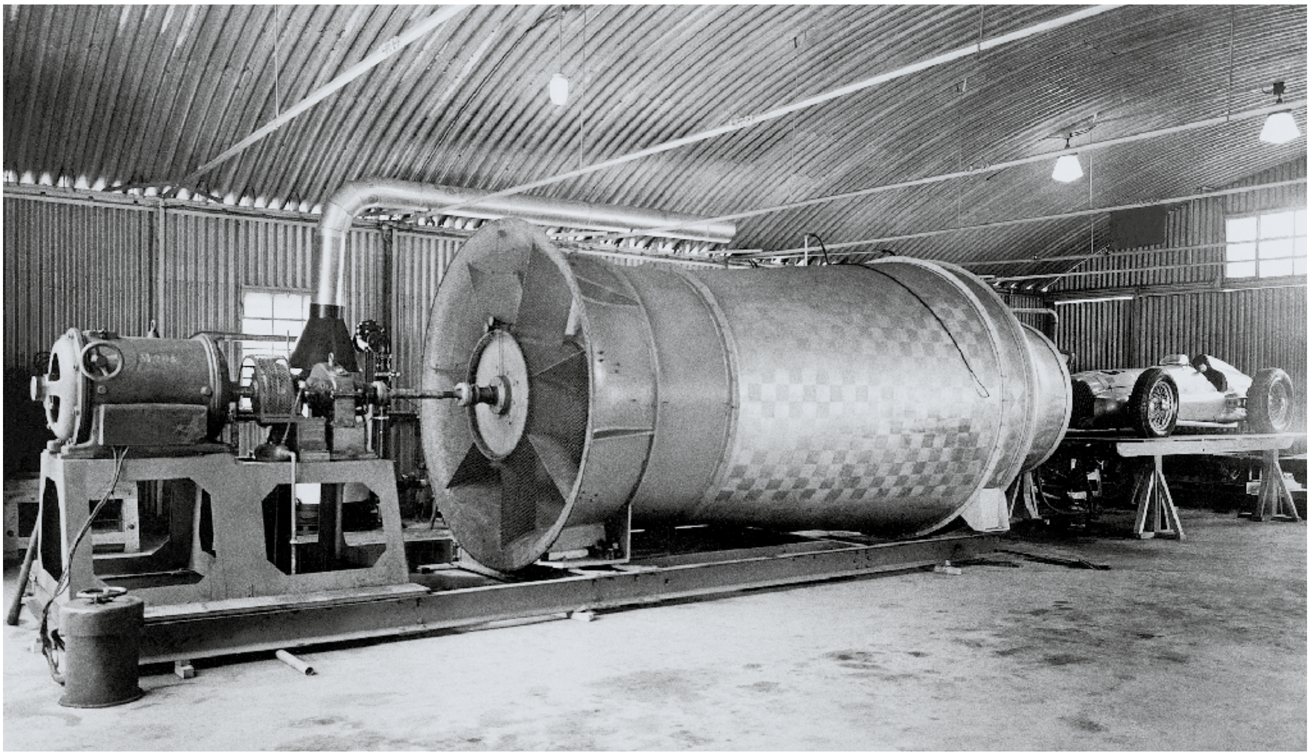
The temperatures generated during fuel combustion (up to 2,000°C) are harmful to the operation of the engine. That is why the engine is cooled to operating temperature. The first type of cooling using water was thermosiphon cooling. The heated, lighter water rises through a manifold into the upper part of the cooler. It is cooled by the airstream, sinks to the bottom, and flows back to the engine. This circuit remains in operation as long as the engine is running. The cooling was supported by fans—so no control was possible. Later, the water circulation was accelerated by a water pump.

Weak points:

- Long warm-up time
- Low engine temperature during the cold season

As engines evolved, a coolant regulator or thermostat was used. The water circulation through the radiator was controlled depending on the coolant water temperature. In 1922, it was described as follows: "The purpose of these devices is to warm up the engine quickly and prevent it from cooling down." We are already talking about a thermostat-controlled cooling system with the following functions:

- Short warm-up time
- Operating temperature kept constant



BEHR wind tunnel 1937

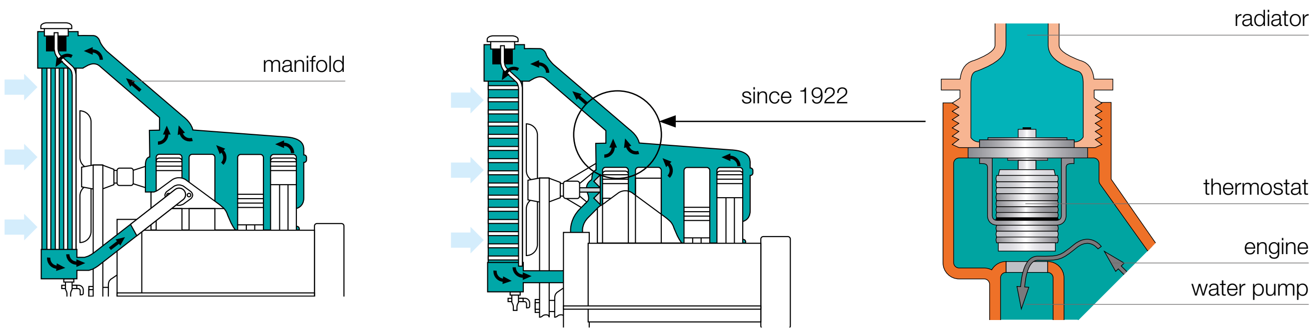
MAHLE climatic wind tunnel today

Modern engine cooling

The thermostat and the resulting "short-circuited" coolant circuit brought about a crucial improvement in engine cooling. As long as the desired operating temperature of the engine is not reached, the water does not flow via the radiator, but passes back into the engine by a short route. Only when the desired operating temperature is reached does the thermostat open the connection via the radiator. To this day, all systems have featured this control.

The operating temperature of the engine is of vital importance not only for performance and consumption, but also for low emissions.

To cool an engine, use is now made of the fact that pressurized water starts to boil not at 100°C but at 115°C to 130°C. So the cooling circuit is under a pressure of 1.0 to 1.5 bar. We are talking about a closed cooling system. For this purpose, the system has an expansion tank that is only about half filled. Instead of just water, a mixture of water and coolant additive is used as the cooling medium. We are now talking about coolant that has antifreeze properties as well as an increased boiling point and protects engine and cooling system components from corrosion.



Around 1910 with water pump

Cooling systems

The engine cooling system

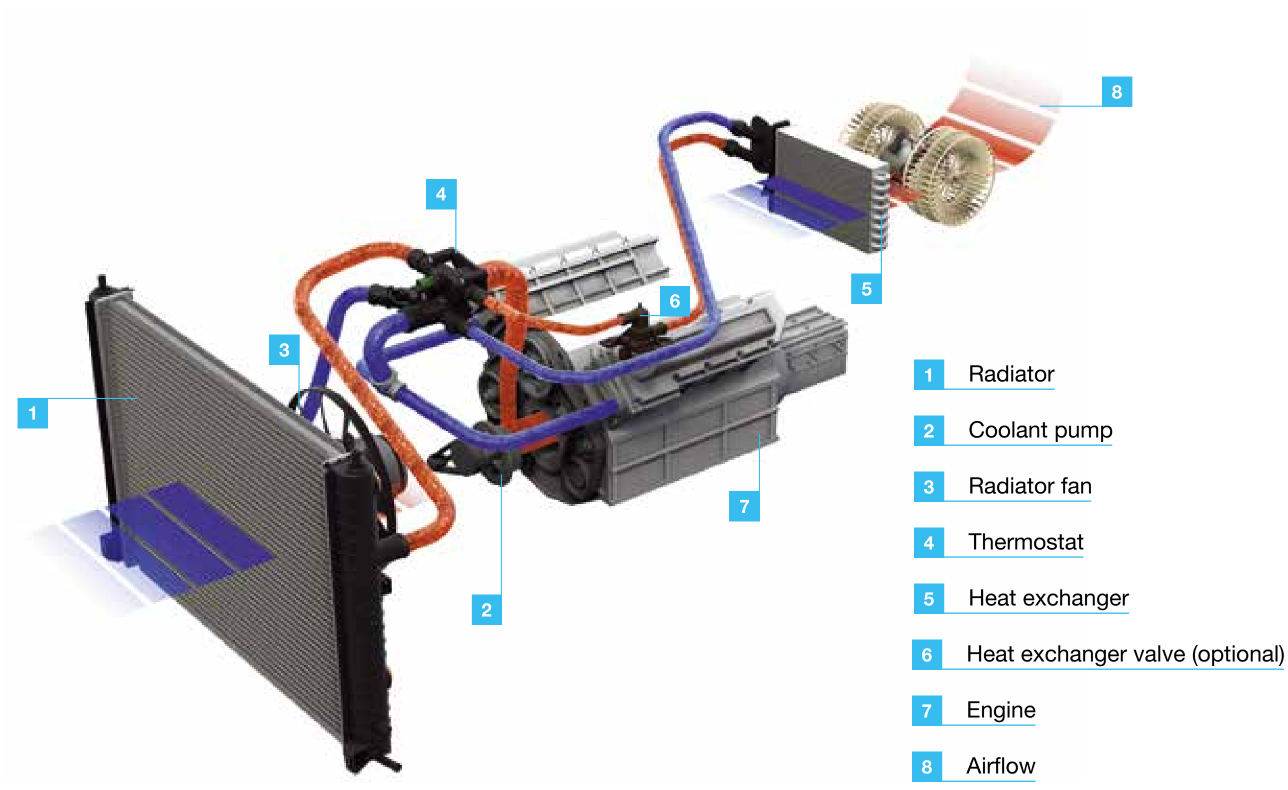
With the engine compartment becoming more and more compact, housing the components and dissipating the enormous amounts of heat poses a significant challenge. In order to cool down the engine compartment, high demands are placed on modern cooling systems. As a result, there has recently been great progress in the field of cooling.

The requirements placed on the cooling system are:

- Shorter warm-up phase
- Rapid cabin heating
- Low fuel consumption
- Improved component service life

All engine cooling systems are based on the following components:

- Radiator
- Thermostat
- Coolant pump (mechanical or electrical)
- Expansion tank
- Lines
- Engine fan (V-belt driven or Visco®)
- Temperature sensor (engine control/display)



Radiator

Radiator

Engine cooling began in 1905. The combustion temperature in the engine at that time was around 600°C to 800°C. Steel radiators were used around the turn of the century until about 1938; after that, metal radiators (copper/brass) appeared. Disadvantage: high weight and limited supply, meaning a high material price.

Requirements for the radiator:

- High power density
- Adequate strength
- Long-lasting corrosion resistance
- Low manufacturing costs
- Environmentally sound production

Design:

- Water tank made of GFP = glass fiber-reinforced polyamide
- Increasingly from aluminum

Task:

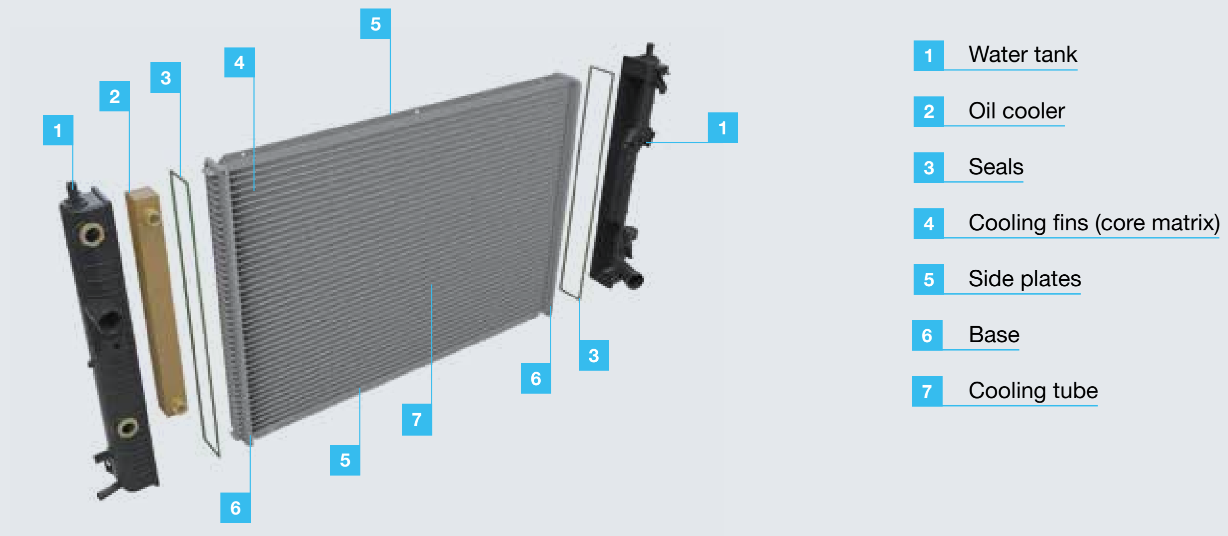
- To cool the coolant in the engine circuit

Advantages:

- Precise fitting for easy installation
- Optimal efficiency
- Tailored to customer specifications (OEM)

Typical design

The oil cooler can also be a separate component of the radiator. The individual parts are assembled to give the radiator its shape. The cooling takes place via the cooling fins (core matrix), whereby the air takes heat from the coolant as it flows through. The coolant flows from top to bottom, called downdraft, or from right to left or vice versa (crossflow). Both variants must have enough time and a sufficiently large cross section to allow the air to cool the coolant effectively.

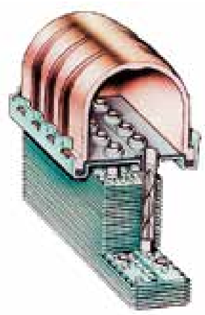


Designs

There are two typical designs: brazed and mechanically joined. Both types are used with downdraft cooling. The first radiators were equipped with brass water tanks and later with plastic tanks. Crossflow radiators are 40% smaller than downdraft radiators and are used in current passenger cars where a flatter design is required. The water tank is fastened and sealed with corrugated crimped edging developed by MAHLE. Another type of fastening is tab flanging. Downdraft radiators are used in taller passenger cars (cross-country vehicles, etc.) and commercial vehicles. There are essentially two different methods for manufacturing radiators: the components can be either mechanically joined or brazed. The technical performance data for the two production processes is virtually identical. However, the mechanically joined version has a lower weight. It is ultimately up to the vehicle manufacturers to decide which process will be used in series production.

The design of the radiator's tube/fin geometry determines its performance. The available installation space in the vehicle must be taken into consideration.


Brazed


Mechanically joined

All-aluminum radiator

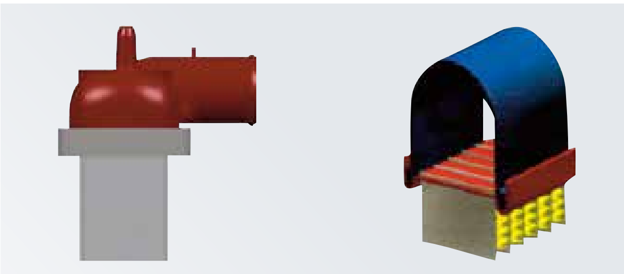
All-aluminum radiator

As can be seen here, the core depth is considerably reduced in the all-aluminum design. This design helps keep the overall depth of the cooling module low. For example, the all-aluminum radiator of the Audi A8 is 11% lighter and has a 20 mm smaller installation depth.

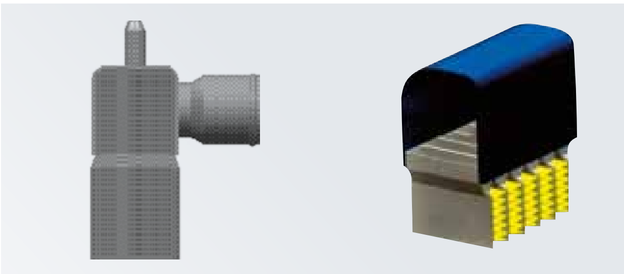
This construction offers the following properties:

- The upper base is no longer needed
- The core depth is equal to the radiator depth
- 5%–10% weight reduction
- Greater operational stability
- Burst pressure 5 bar
- Recyclable in its entirety
- Transport damage is reduced (overflow nozzle)
- Different pipe types can be used
- Round tube offers higher performance with turbulence insert
- Oval tube (offers more space for cooling)
- Flat tube, mechanical production, paneled (even more space and only a single row needed)
- Flat tube, brazed, without flux (best cooling, fins fit 100%), but cost-intensive
- Special aluminum alloy used (core matrix)
- Temperature 600°C to 650°C then cool down to approx. 130°C (tensions are compensated)

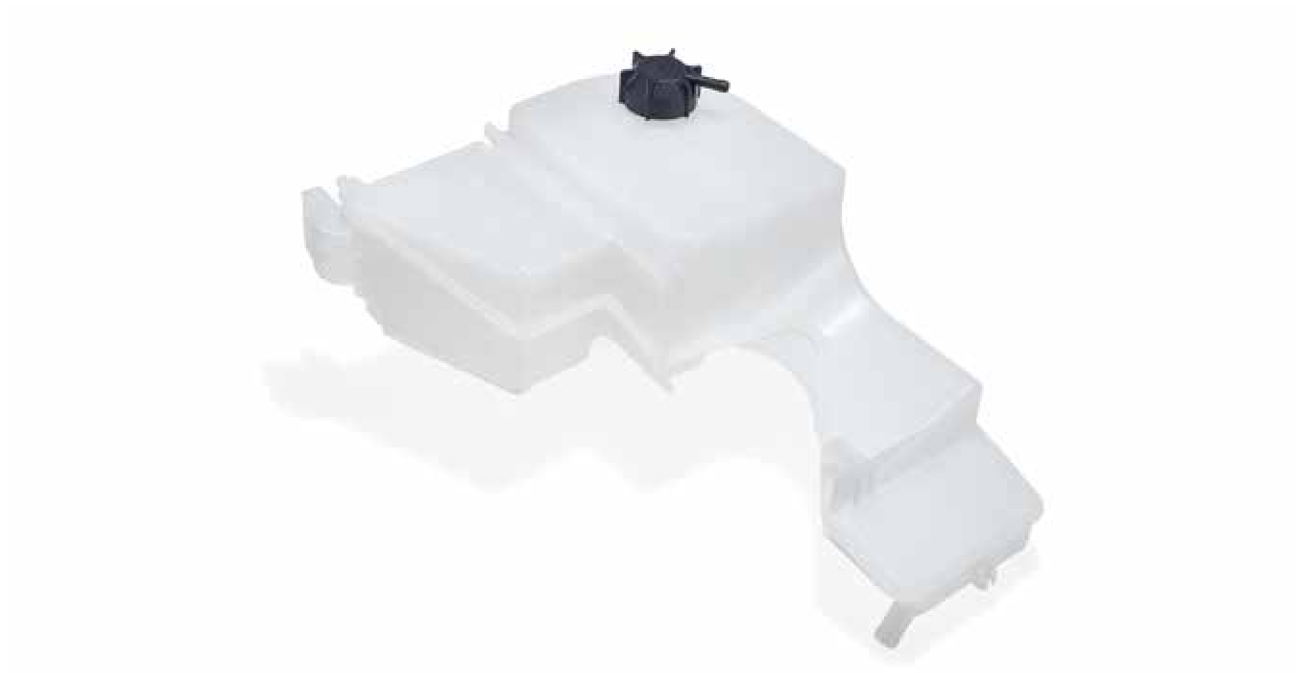
This comparison shows the difference between a radiator with a standard base and an all-aluminum radiator. It can be clearly seen that the overall depth is considerably reduced, saving space when installed in a modern cooling module.



Core depth 40 mm, overall depth 63.4 mm



Core depth 40 mm, overall depth 40 mm



Expansion tank for commercial vehicles

Expansion tank

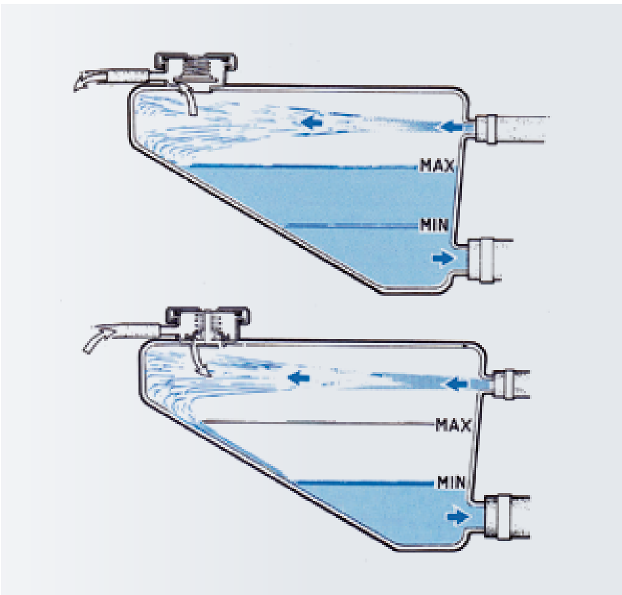
To prevent local overheating of the components, the coolant circuit must be bubble-free. The coolant enters the tank at high speed and exits at low speed (different nozzle diameters).

In comparison, commercial vehicle expansion tanks have three chambers and a large volume of water—e.g., a coolant volume of 8 liters. The expansion tank is designed to absorb expanded coolant from the coolant circuit. The pressure is reduced by a valve, and the system pressure is therefore kept at a predefined value.

Expansion tank for passenger car

Function

A high coolant temperature leads to a pressure increase in the cooling system as the coolant expands. The coolant is forced into the tank. The pressure in the tank increases. The pressure-relief valve in the cap opens and allows air to escape. When the coolant temperature normalizes, a vacuum is created in the cooling system. Coolant is sucked out of the tank, which also creates a vacuum in the tank. As a result, the vacuum compensation valve in the filler cap of the tank opens. Air flows into the tank until the pressure equalizes.



How an expansion tank works

Electronically controlled thermostat with wax element

Thermostat

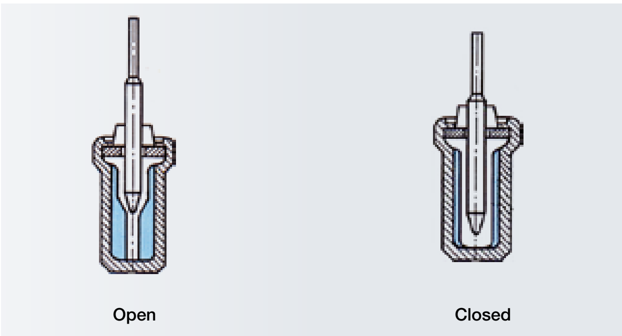
Thermostats control the temperature of the coolant and thus also the engine temperature. Mechanical thermostats have not changed much over the years and are still being installed today. They function by means of an expanding wax element that opens a valve and returns the coolant to the radiator for cooling. The thermostat opens at a certain temperature that is predefined for the system and cannot be changed. Electronically controlled thermostats are regulated by the engine control unit and open according to the operating conditions of the engine. Electronically controllable temperature regulators help to reduce fuel consumption and pollutant emissions by improving mechanical engine efficiency.

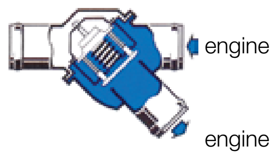
Advantages:

- Reduction of fuel consumption by approx. 4%
- Reduction in pollutant emissions
- Improved comfort (by improving the heating performance)
- Longer engine service life
- Preservation of the flow conditions and thermodynamic conditions
- Demand-oriented temperature regulation
- Very high speed of temperature change
- Lowest overall installed size increase (<3%)

Function

When heated above 80°C, the wax filling melts. As the volume of the wax increases, the metal container moves on the working piston. The thermostat opens the radiator circuit and simultaneously closes the by-pass loop. If the temperature drops below 80°C, the wax filling solidifies. A return spring pushes the metal container back to its starting position. The thermostat closes the supply to the radiator. The coolant flows directly back to the engine via the short-circuit line.





Thermostat with wax element

Coolant pump

Coolant pumps

Coolant pumps transport the coolant through the circuit and increase the pressure. Coolant pumps also undergo technical innovations, but there are still a large number of passenger cars and commercial vehicles with belt-driven coolant pumps on the market. Electronically controlled coolant pumps are the next generation. These coolant pumps are driven on demand, similar to the compressor in the air conditioning circuit, allowing an optimal operating temperature to be reached.

Timing belt kit with coolant pump

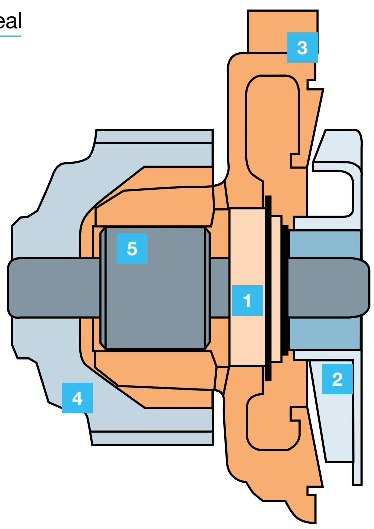
1 Axial mechanical seal

2 Impeller

3 Housing

4 Drive wheel

5 Roller bearing



Coolant pumps consist of five main assemblies

The drive wheel and impeller are mounted on a common shaft. A mechanical seal seals the pump shaft from the outside. The rotating movement of the impeller transports the coolant through the cooling system.

The service life of a coolant pump is heavily influenced by the following factors:

- Proper installation
- Care and maintenance of the cooling system
- Coolant quality
- Condition and functional capability of the drive belt and the connected auxiliary aggregates

Electric coolant pump

Electric coolant pumps

Mechanical coolant pumps, which are driven directly by the engine, continuously deliver coolant while the engine is running, even when there is no need for cooling. In contrast, electric coolant pumps and their integrated electronic control are variably activated according to the required cooling performance. They can be used as main, minor, or circulation pumps. They operate independently of the engine and as required.

During a cold start, an electric coolant pump initially pumps no coolant. This allows the engine to reach its operating temperature faster. Even when idling or after turning off the engine, an electric coolant pump can deliver sufficient cooling performance, as it is not connected to the engine speed. This demand-driven cooling of the engine lowers the power requirement and thus reduces friction losses and fuel consumption. Electric coolant pumps thus help to lower emissions in modern cooling systems.

Another advantage is that electric coolant pumps can be installed individually, outside the engine. They are relatively light and—thanks to the brushless design—maintenance-free. With an operating voltage of 12 to 360 volts, they currently achieve an output of 15 to 1000 watts. The electric motor of the coolant pump is cooled by coolant. The continuously variable control is achieved by means of a pulse-width-modulated (PWM) signal. In this way, the delivery volume can be controlled independently of the engine speed, according to the actual demand, and the coolant temperature can be kept constant as required by the system.

By integrating them into the electrical system, it is possible to carry out diagnostics on electric coolant pumps. Depending on the type of drive (combustion engine, hybrid, electric) and system, one or more pumps can be installed in the vehicle.

Electric coolant pump for BMW

Electric coolant pumps have a wide range of applications:

- Cooling the engine
- Charge air cooling
- Cooling the exhaust gas recirculation
- Cooling of drive and battery in hybrid and electric vehicles
- Transmission cooling
- Cooling of various parasitic loads

Cabin heat exchangers

Cabin heat exchangers

The heat exchanger supplies heat, which is transported into the vehicle cabin with the airflow of the blower. If air conditioning is available, which is usually the case today, a blend of cold and warm air is produced by the climate control system. Here, all three factors come together: Heat, cold, and the corresponding control = air conditioning of the vehicle cabin.

Characteristics of an all-aluminum heat exchanger:

- Fully recyclable
- Ensures the desired cabin temperature
- Brazed heat exchanger in all-aluminum design
- Reduced space requirement in the vehicle cabin
- High heating performance
- End caps brazed and not clamped
- Installed in the heating box
- Fin-and-tube system
- Gill fields in the fins increase performance
- State-of-the-art, like the radiator: all-aluminum

All-aluminum heat exchanger

Engine fans

The engine fan serves to transport ambient air through the radiator and over the engine. It is driven by the V-belt or, in the case of an electrically driven fan, by a controlled electric motor. The Visco® fan is mainly used in commercial vehicles but is also found in the passenger car sector. The engine fan ensures that a sufficient volume of air flows through to cool down the coolant. With the V-belt-driven fan, the air volume is dependent on the engine speed. It differs from the condenser fan in that it is driven continuously. The Visco® fan is controlled by the operating temperature.

Visco® fans

Principle of operation

Full switch-on point at approx. 80°C. Filled with silicone oil as drive medium (30–50 ml), switched on by bimetal, and actuated via the thrust piece.

History

Rigid (permanently driven), requires a large amount of energy (HP), is noisy, and has a high consumption. On the other hand, electric fans (passenger cars) offer more economical consumption, are low-noise, and have a lower energy requirement. The development goals were low consumption and less noise—e.g., noise reduction through the use of shielded fans.

Ongoing development resulted in the electronic Visco® clutch, which has the following properties:

- Continuously variable control
- Control via sensors
- Controller processes data—e.g., coolant, oil, charge air, engine speed, retarder, climate

This results in demand-based cooling, improved coolant temperature levels, lower noise, and reduced fuel consumption. In the passenger car sector, the fans were previously two-piece, with the Visco® clutch and fan wheel bolted together. Today they are rolled and therefore no longer repairable.

> Around 50 years ago, BEHR developed the Visco® fan and registered the Visco® trademark. Since MAHLE acquired a majority holding in BEHR and the trademark rights were transferred, Visco® products have been produced and marketed under the MAHLE name. Only fans and clutches of this type produced by MAHLE may be marketed with the prefix Visco®.

Complete Visco® fan (clutch and fan wheel)

Visco® clutch

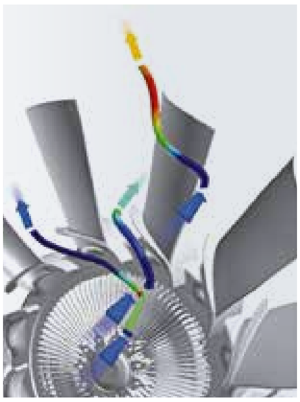
The electronic Visco® clutch

The drive disk and the flanged shaft transmit the power of the engine. The fan is also securely connected to this component. Circulating silicone oil ensures the transmission of power by both assemblies. The valve actuating lever controls the oil circuit between the reservoir chamber and the working chamber.

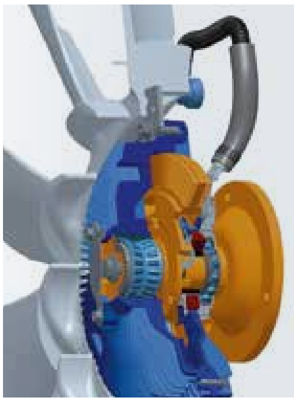
The flow of silicone oil from the reservoir chamber to the working chamber and back takes place between two bores: the return bore in the housing and the supply port in the drive disk.

The valve actuating lever controls the engine management via pulses to the solenoid assembly. The hall-effect sensor determines and informs the engine management about the current speed of the fan. A regulator sends a pulsed control current to the solenoid assembly that controls the valve actuating lever, which in turn controls the oil flow and oil quantity. The more silicone oil there is in the working chamber, the higher the speed of the fan. When the working chamber is empty, the fan is in idle mode and there is a slip of about 5% at the drive.

Visco® clutch



Fan wheel air duct



Electronically controlled Visco® clutch with fan

Electric radiator fan with shroud

Electric radiator fans

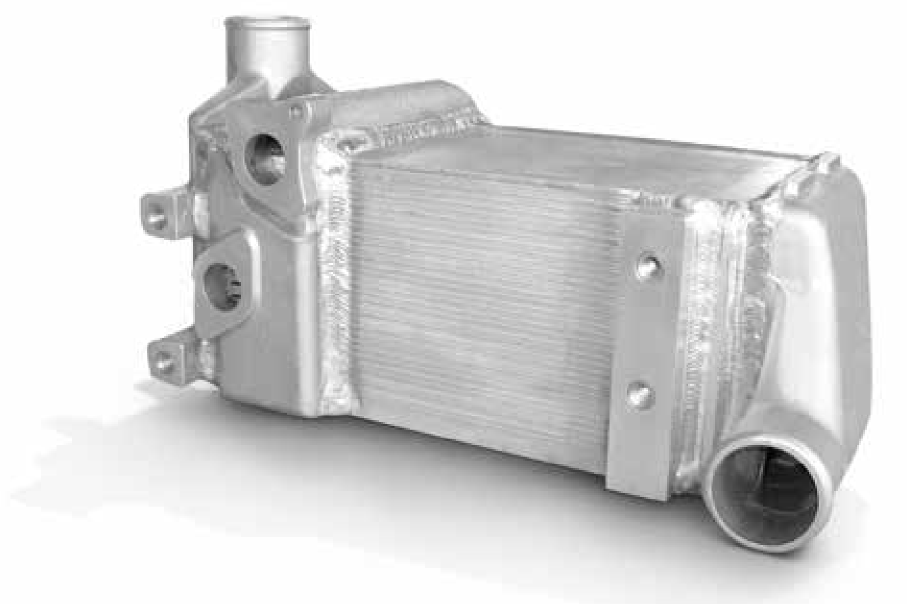
In passenger cars, electric fans are mostly used. They are often deployed as extractor fans, but sometimes also as pressurizing fans. By allowing a greater flow of air to pass through the engine radiator when the fan is operating, they ensure that the coolant is kept at an optimal temperature under all vehicle operating conditions. In the front section of the vehicle there are usually other coolers (e.g., charge air, steering, fuel, condenser) whose media (air, oil, fuel, refrigerant) are also cooled down by electric fans.

The fan or fans (double fan) are controlled via pressure or temperature switches or a control unit. This allows the fan speed to be controlled stepwise (switch) or continuously (pulse-width-controlled) according to the operating conditions. With electronically controlled fans, the control unit is often located near the fan unit. With the help of a diagnostic tool/oscilloscope, the fault memory can be read out or the control functionality checked.

Causes of failure include mechanical damage (crash, bearing damage, broken guide vane) and electrical faults (contact fault, short circuit, defective switch/control unit).

The electric radiator fan or fans are usually mounted on fan shrouds. These have the task of guiding the air flowing through the radiator to the fan in a targeted manner and as free from flow losses as possible. For this reason, the fan shroud is also mounted as close as possible to the radiator.

Other cooling systems



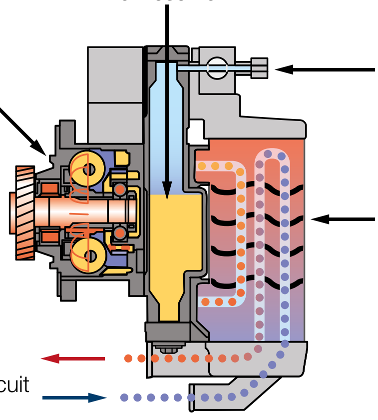
All-aluminum oil cooler for hydrodynamic retarders

Oil coolers for engine, transmission, and hydrodynamic retarders

Cooling as well as faster heating of engine oil and transmission oil (e.g., automatic transmission, retarder) is ensured by built-in or attached coolers (engine or transmission) in the water tank. The two main types are tube or disk oil coolers in an all-aluminum or steel design.

Advantages:

- Cooling of oils with a high thermal load
- Oil change intervals are extended; the service life of the engine is increased
- Low space and weight requirements thanks to all-aluminum design
- Compact design due to powerful stacked plates with large-scale surface cooling



Retarder with attached oil cooler

Power steering cooler

Fuel cooler

Power steering cooling

The power steering oil must also be cooled—otherwise, the efficiency of the power steering is impaired, and the steering becomes either too heavy or too light.

Properties:

- All-aluminum with quick-release coupling connections
- Pressure more than 8 bar with an oil inlet temperature of –40°C to +160°C
- Test pressure 20 bar with a burst pressure of 50 bar

Fuel cooling

Fuel cooling is mainly used in diesel engines. The fuel is cooled in order to lower the inlet temperature at the pump nozzle or common rail. Otherwise, the high pressure would cause an excessive increase in fuel temperature, impairing engine performance by premature combustion in the combustion chamber.

Charge air cooler

Charge air cooling

The trends toward increasing engine performance and downsizing are leading to an increasing proportion of turbocharged engines in passenger cars, which means that today's engines are generally turbocharged using cooled charge air. The higher charge air density achieved in this way increases the output and efficiency of the engine. However, it is not only the number of turbocharged engines that is increasing, but also—due to the further required reductions in consumption and emissions—the demands on the charge air cooling capacity. These demands can be met by cooling the charge air using coolant instead of air. However, because of the system costs, this technology has so far been reserved for the upper passenger car price segment. New developments also make it possible to control the charge air cooling. This makes it possible to reduce the NO_x and HC emissions, while increasing the effect of the exhaust gas aftertreatment. Aside from improving the cooling capacity, there is a further requirement for charge air cooling: controlling the temperature of the engine process air by regulating the charge air cooling. This temperature control is made necessary by the steadily increasing demands on exhaust gas aftertreatment—the temperature of the charge air plays an important role here. So cooling the charge air with coolant also offers decisive advantages when it comes to commercial vehicles.

Types:

Air cooled and coolant cooled, direct and indirect

Task:

Increasing the performance of the engine by charging (more combustion air, higher oxygen content)

Properties:

- Higher dynamic cooling capacity
- Improved engine efficiency due to the increase in charge air density
- Lower combustion temperature, resulting in better emissions values
- Fewer nitrogen oxides at –40°C to +160°C
- Test pressure 20 bar with a burst pressure of 50 bar

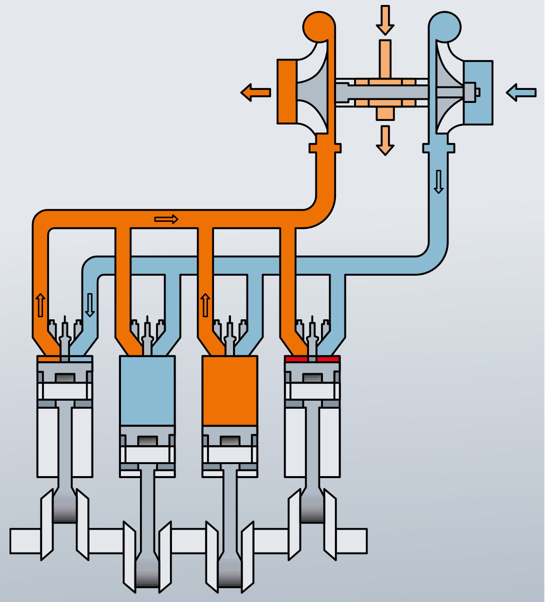
The performance of a combustion engine depends on the amount of fuel burned

↓

1 kg fuel requires 14.7 kg air for complete combustion in a gasoline engine
Diesel engine >14.67 kg air for 1 kg fuel

↓

Turbocharging combustion engines is therefore an effective means of increasing performance
Turbocharged engine <-> naturally aspirated engine



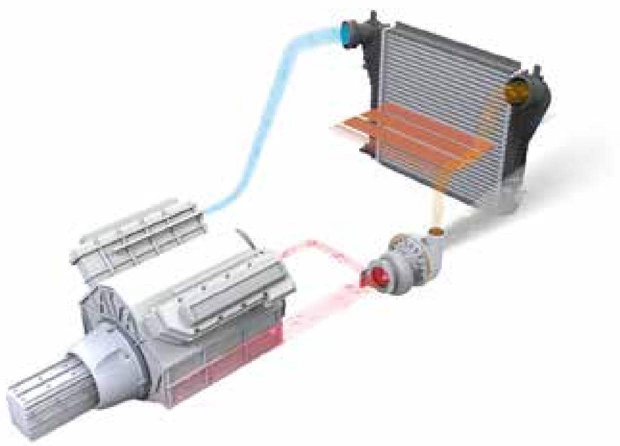
Exhaust gas turbocharging

Basics: exhaust gas turbocharging

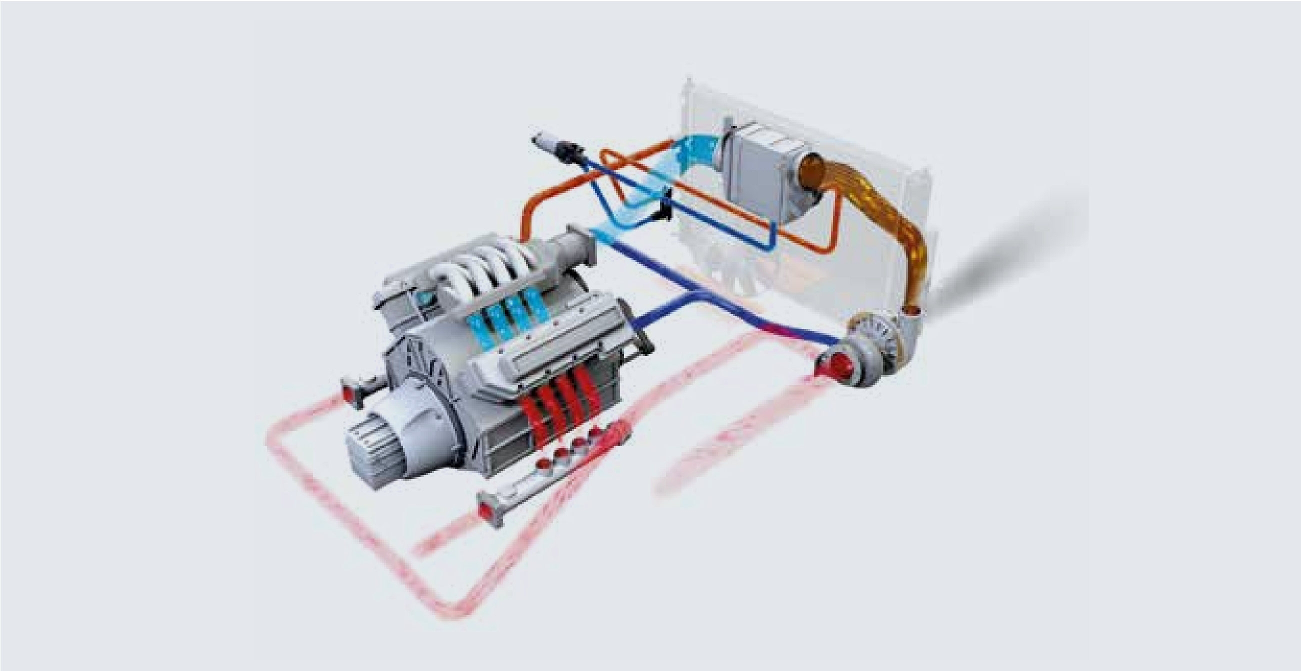
The performance of a combustion engine depends on the amount of fuel burned. 1 kg fuel requires 14.7 kg air for complete combustion in gasoline engines—this is the stoichiometric ratio. Turbocharging combustion engines is an effective means of increasing performance.

Requirements: an increase in cooling performance

In passenger cars, the rising demand for cooling performance conflicts with the increasingly restricted installation space in the vehicle's front end. Compact charge air coolers still dominate today. One solution to the problem of the small installation depth is to enlarge the compact charge air cooler so that it becomes a flat charge air cooler mounted in front of the radiator, as is standard in heavy-duty commercial vehicles. Consequently, the use of this design is increasing. However, this is not possible in many vehicles because the required installation space has already been allocated or is no longer available because of other requirements—such as pedestrian protection. The conflict between installation space and power requirements can be resolved with two new systems: charge air precooling and indirect charge air cooling.



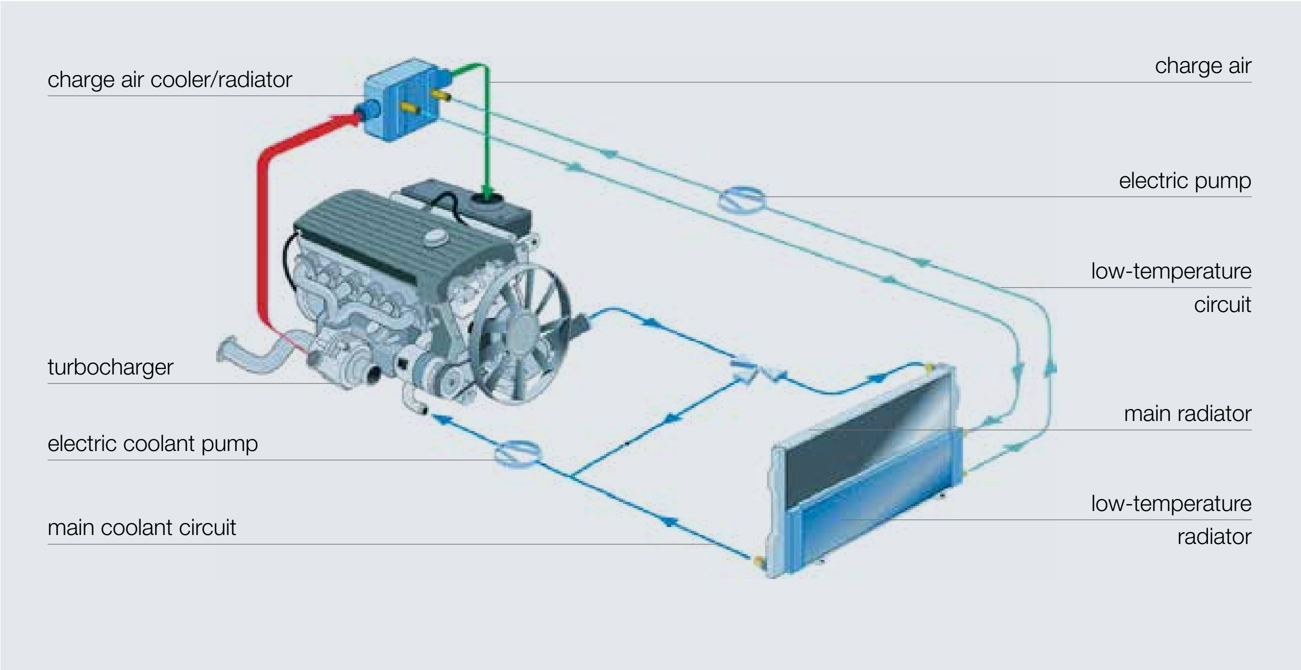
Charge air ducting when using direct charge air/air cooling (for example)



Charge air ducting when using direct charge air/coolant cooling (for example)

Charge air precooler

By using the new charge air precooler, which is fed with coolant from the engine circuit, some of the charge air waste heat is shifted from the charge air cooler to the radiator. Since the additional charge air waste heat, which is produced as a result of the performance increase, can be dissipated through the precooler, the concept of a block-shaped charge air cooler can be retained. The charge air precooler, also a compact cooler, is placed between the turbocharger and the charge air/air cooler. Thanks to the charge air precooling, the performance of an existing concept can be significantly increased. The required overall installed size of a charge air cooler/radiator is 40% to 60% of a charge air/air cooler.



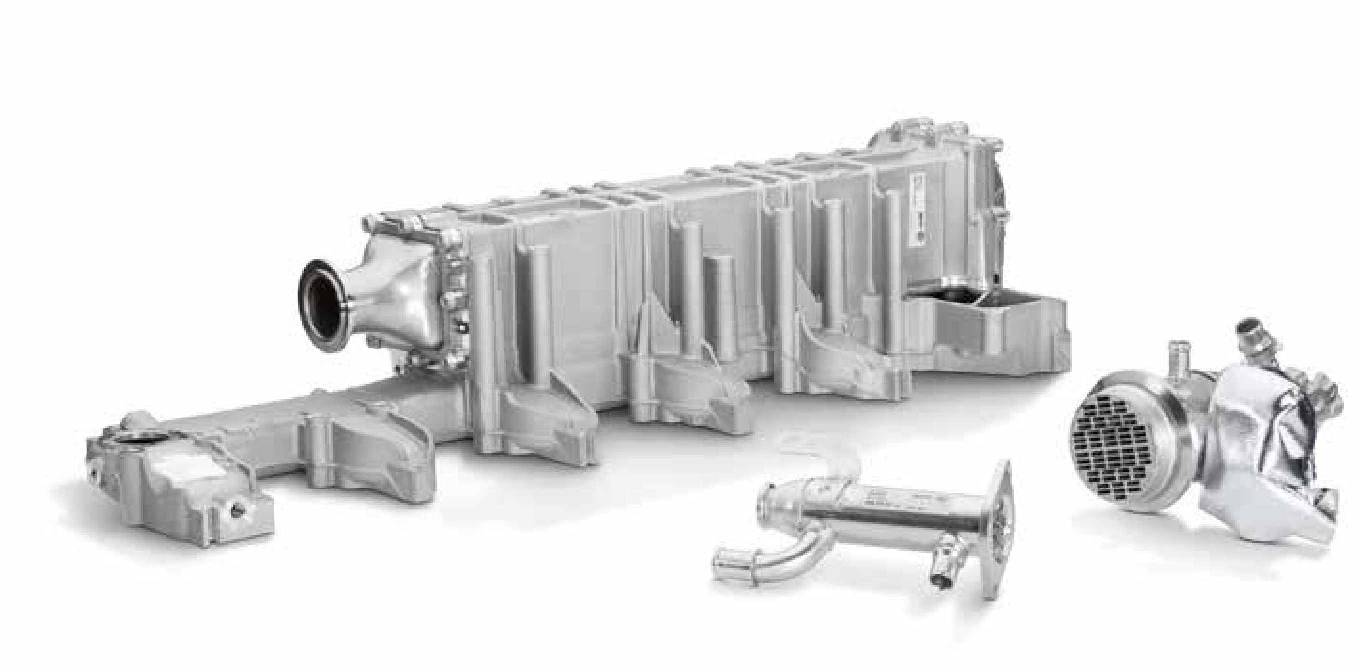
Coolant circuit in indirect charge air cooling

Indirect charge air cooling

The second way of resolving the conflict between installation space and power requirements is the use of indirect charge air cooling. In the passenger car, this cooling system generally consists of a complete coolant circuit that is independent of the engine cooling circuit. A low-temperature radiator and a charge air cooler/radiator are incorporated in this circuit. The charge air's waste heat is initially transferred to the coolant and then dissipated to the ambient air in the low-temperature radiator. This cooler is integrated in the vehicle's front end, where the charge air/air cooler is located in conventional air-cooled charge air cooling. Since the low-temperature radiator needs significantly less space than a comparable charge air/air cooler, space is freed up in the front end. This also means that the bulky charge air lines from the vehicle front end to the engine are no longer needed. This significantly simplifies the overall packaging in the front end, improving the cooling airflow through the engine compartment accordingly.

Compared with charge air precooling (direct), indirect charge air cooling results in the following positive effects:

- Significantly reduced charge air pressure loss
- Improved engine dynamics thanks to the lower volume of charge air
- Higher dynamic cooling capacity
- Improved engine efficiency due to increase in charge air density



EGR coolers of various types

Coolers for exhaust gas recirculation (EGR)

One way of meeting the new Euro 6 limits for nitrogen oxide emissions (NO_x) is cooled exhaust gas recirculation (EGR). Some of the primary exhaust gas flow between the exhaust manifold and the turbocharger is extracted, cooled in a special heat exchanger (EGR cooler), and fed back into the intake air. This decreases the combustion temperature in the engine, reducing the formation of nitrogen oxides.

EGR cooler

The EGR cooler is made of stainless steel or aluminum and has several connections via which hot exhaust gases and coolants can flow into the cooler. After the exhaust gases have been cooled down in the cooler, they leave the cooler and are fed in metered doses to the intake system and thus to the combustion chamber. This leads to a reduction in nitrogen oxide emissions even before reaching the catalytic converter. Pneumatic and/or electric actuators are installed on the EGR cooler to perform the control function.

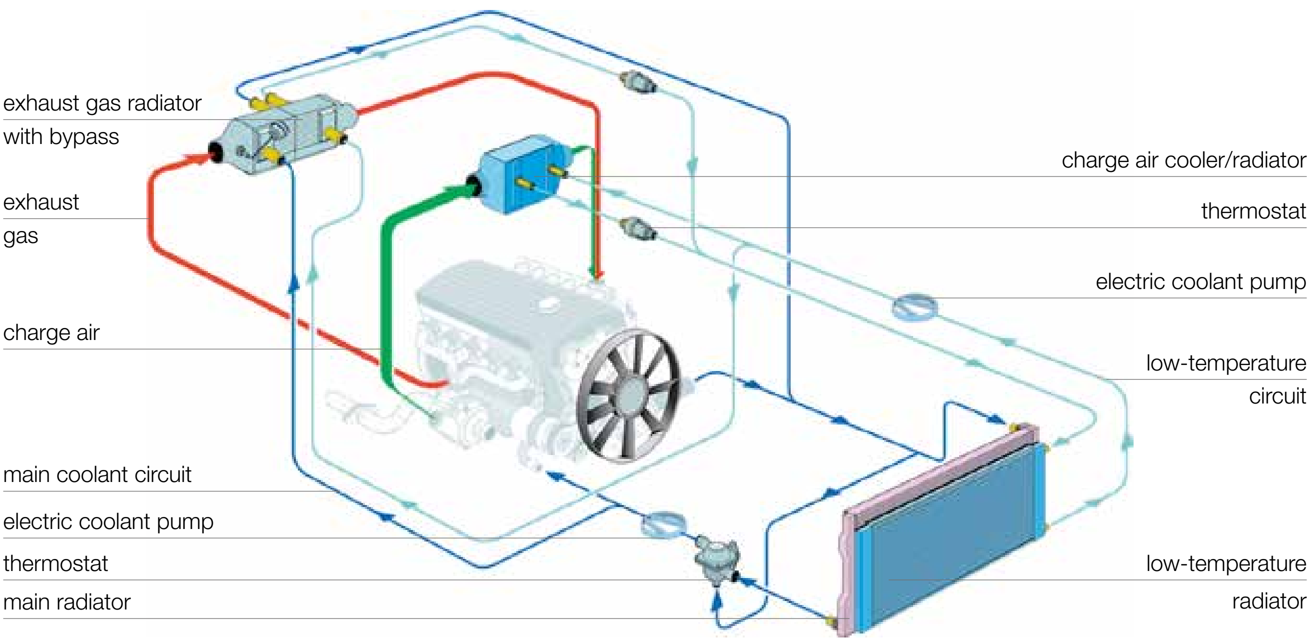
Although the EGR cooler is not a classic wear part, defects due to extreme temperature fluctuations or missing or aggressive coolant additives, for example, can lead to internal or external leaks. Moreover, it is possible that the actuators will fail.

Intake air and temperature management

Air temperature control for the combustion process in the engine

After a cold start and at extremely low outside temperatures while driving, it is advisable to suspend the charge air cooling. The engine and catalytic converter then reach their optimal operating temperature more quickly, resulting in fewer cold-start emissions, mainly hydrocarbons (HC). With a charge air/air cooler, this is only possible by means of a bypass on the charge air side—involving great expense. With indirect charge air cooling, on the other hand, simple control of the coolant volume flow rate not only allows the cooling of the charge air to be suspended, but also makes it possible to control its temperature. By linking the coolant circuit for charge air cooling with the circuit for engine cooling and with intelligent control of the coolant flow rates, indirect charge air cooling can be extended to cover charge air temperature control. Either the hot coolant of the engine circuit or the comparatively cooler coolant of the low-temperature circuit can flow through the charge air cooler.

Regulation of the charge air temperature is important for exhaust gas aftertreatment by particulate filters and catalytic converters. Both require a certain minimum exhaust gas temperature for optimal operation. In the case of the catalytic converter, this minimum temperature is identical to its startup temperature, while in the case of the particulate filter it is identical to the regeneration temperature required for the combustion of the accumulated soot. When the vehicle is in partial-load operation (urban traffic, stop and go) these exhaust gas temperatures are not always reached. Even in these cases, emissions can be reduced by stopping cooling or even heating the charge air, because in any case the temperature of the exhaust gas is increased. Both options are most easily achieved by means of indirect charge air cooling.



Subsystems of intake air temperature management (ATM)

Indirect charge air cooling

Charge air cooling increases the air density in the cylinder and reduces the combustion temperature. In ATM, the charge air is not cooled by air as usual, but by a liquid coolant, a water-glycol mixture as used for engine cooling. The charge air's waste heat is initially transferred to the coolant and then dissipated to the ambient air in a low-temperature radiator.

Advantages of indirect charge air cooling:

- Higher cooling capacity than with conventional charge air/air cooling
- Higher cylinder volumetric efficiency due to lower charge air pressure loss
- Shorter response time of the charge air cooler due to its placement near the engine

Cooled exhaust gas recirculation

It causes a reduction of the oxygen concentration in the cylinder, lowering the temperature and speed of combustion. Intake air temperature management (ATM) is suitable for both high-pressure and low-pressure exhaust gas recirculation. In high-pressure exhaust gas recirculation, the exhaust gas is extracted upstream of the turbocharger, cooled in the exhaust gas cooler, and then mixed into the charge air. If the intake air temperature needs to be raised to improve exhaust gas aftertreatment, the exhaust gas cooler is bypassed. Low-pressure exhaust gas recirculation is an option for the future. Here, the exhaust gas is not extracted upstream, as in the case of high-pressure exhaust gas recirculation, but downstream of the exhaust gas turbocharger and also the particulate filter. It is then cooled and mixed with the charge air upstream of the turbocharger's compressor.

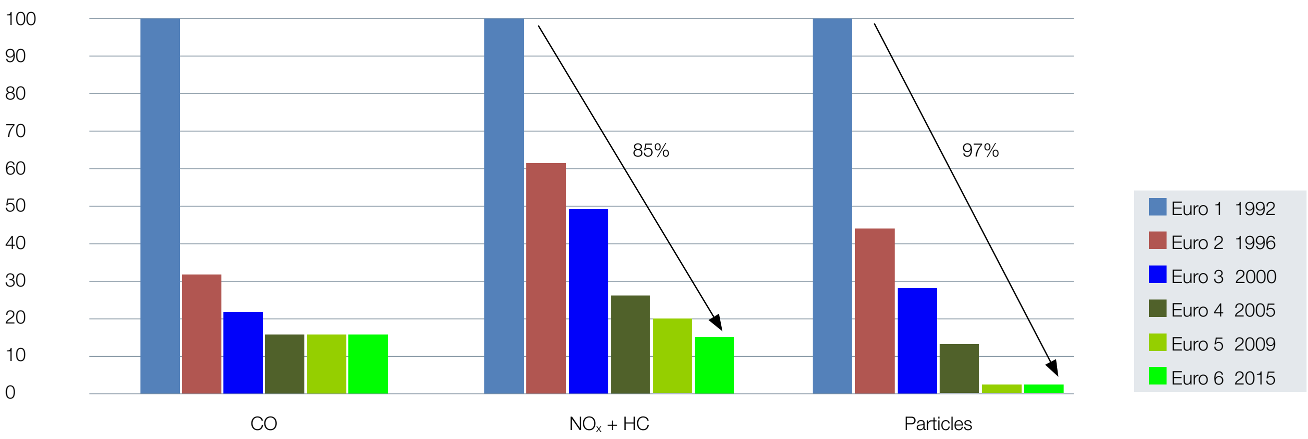
Charge air heating

With ATM, the intake air can be heated in four ways: by discontinuing charge air cooling or exhaust gas cooling, by discontinuing both, or by heating the charge air. For heating, a partial flow of hot coolant is branched off from the engine cooling circuit and guided to the charge air cooler. In tests with a 2-liter diesel unit on an engine test bench with a brake mean effective pressure of 2 bar, the exhaust gas temperatures downstream of the turbine were measured. These measurements were obtained by varying the intake air temperatures according to the possibilities described above. As a result of interrupting the charge air cooling, the lowest exhaust gas temperature increase was approx. 6°C. If the charge air was heated with the engine coolant (thermostat temperature), which is around 85°C, the exhaust gas temperature downstream of the turbine rose by approx. 16°C. The maximum potential obtained from heating is probably 20°C. The highest increase of approx. 57°C was produced by interrupting the exhaust gas cooling (switchable exhaust gas cooler). If this is combined with heating the charge air, the exhaust gas temperature can be raised by over 70°C. At a mean effective pressure of 4 bar, an increase of as much as 110°C is possible.

Euro 6 and its significance

For diesel passenger cars, Euro 6 requires a further significant reduction in emissions compared with Euro 4 and Euro 5 for hydrocarbons (HC), nitrogen oxides (NO_x), and particulates. Temperature control of the engine intake air is becoming increasingly important in order to achieve these goals. The intake air temperature management (ATM) system developed by MAHLE reduces emissions at the point of origin, supports exhaust gas aftertreatment, and facilitates the regeneration of the particulate filter. In addition, synergies between the ATM subsystems mean that less installed cooling capacity is required than for current systems, thus saving fuel and installation space.

Diesel passenger car exhaust gas emissions



Operating principle of intake air temperature management (ATM)

The ATM consists of three subsystems: indirect charge air cooling, cooled exhaust gas recirculation, and engine cooling. These subsystems are linked and controlled in such a way that the intake air can be cooled and heated and the combustion temperature raised and lowered. The temperature is lowered by cooling the charge air and exhaust gases and by adding as many exhaust gases to the charge air as possible according to the load case of the engine and reducing the oxygen concentration in the cylinder accordingly. In order to increase the combustion temperature, the charge air and exhaust gas cooling are suspended, and the charge air can also be heated.

Reducing emissions

NO_x: Since NO_x formation is exponentially dependent on the combustion temperature, its reduction results in a significant decrease in NO_x: by around 10% for a temperature reduction of 10°C; fuel consumption decreases by 0.5%–1%. HC and CO: During a cold start, the combustion temperature is usually still low, the combustion is incomplete, and the formation of HC and CO is therefore high. Since the oxidation catalyst has not yet reached its operating temperature in this phase, emissions are produced. In certain situations (urban traffic in winter, stop and go), the combustion and catalyst temperature can drop so low, even during normal driving, that HC and CO emissions are produced. In both cases, the rapid increase in the combustion and therefore the exhaust gas temperature caused by the ATM reduces the formation of HC and CO and promotes their conversion in the catalytic converter. The temperature is increased by stopping the exhaust gas cooling. For this purpose, the exhaust gas cooler is equipped with an integrated bypass and an electric resonance control flap. Measurements on a chassis dynamometer on a turbocharged 1.9-liter diesel engine showed an approximately 30% reduction in HC and CO emissions during cold starts.

Regeneration of the particulate filter

When the particulate filter is full, the accumulated soot must be burned. This also means that the ATM system needs to increase the exhaust gas temperature, which is usually below the soot ignition temperature of 550°C. Soot combustion can also be initiated by lowering the soot ignition temperature—e.g., by means of a fuel additive. A combination of both processes—raising the exhaust gas temperature and lowering the soot ignition temperature—has certain advantages: the amount of additive can be reduced, and the dosing system simplified. However, if the temperature increase generated by the ATM system is combined with postinjection, an additional system for filter regeneration is usually not required.

Energy savings

Different amounts of heat accumulate in the charge air and exhaust gas cooler depending on the engine load. Under partial load, where the exhaust gas recirculation rate can be over 50%, more coolant is required in the exhaust gas cooler than in the charge air cooler. At some partial-load points, e.g., 50 km/h on level ground, the charge air cooler can be dispensed with completely and the full cooling capacity can be made available to the exhaust gas cooler. Under full load, however, virtually the entire cooling capacity must be used for the charge air cooler. By distributing the coolant flows according to demand in this way, the installed cooling capacity and installation space can be reduced considerably—e.g., by up to 10%.

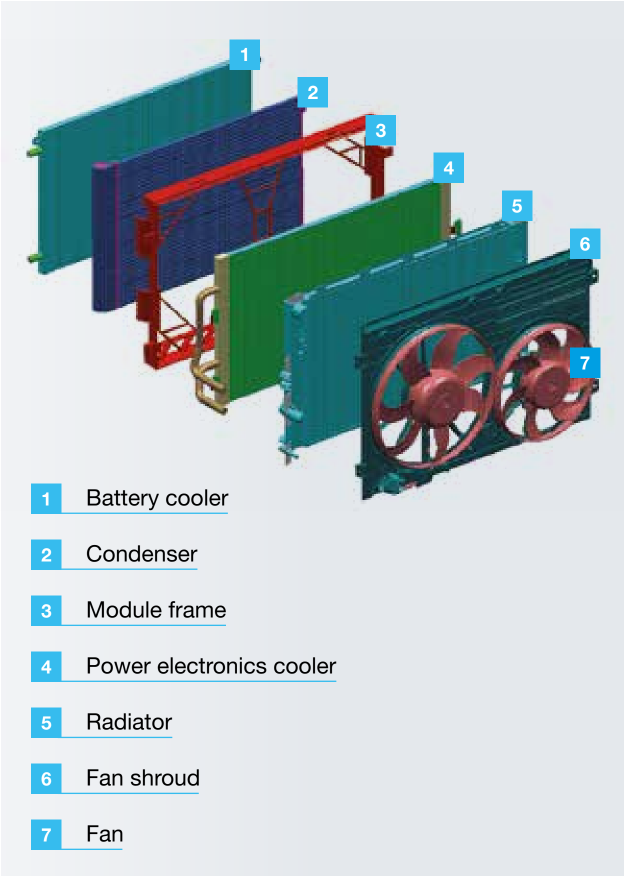
Battery temperature management for hybrid vehicles

The correct temperature plays a key role for batteries with larger capacities. Therefore, at very low temperatures, additional heating of the battery is required to bring it to the ideal temperature range. This is the only way to achieve a satisfactory cruising range when in "electric driving" mode.

To enable this additional heating, the battery is integrated into a secondary circuit. This circuit ensures that the ideal operating temperature of 15°C to 30°C is maintained at all times.

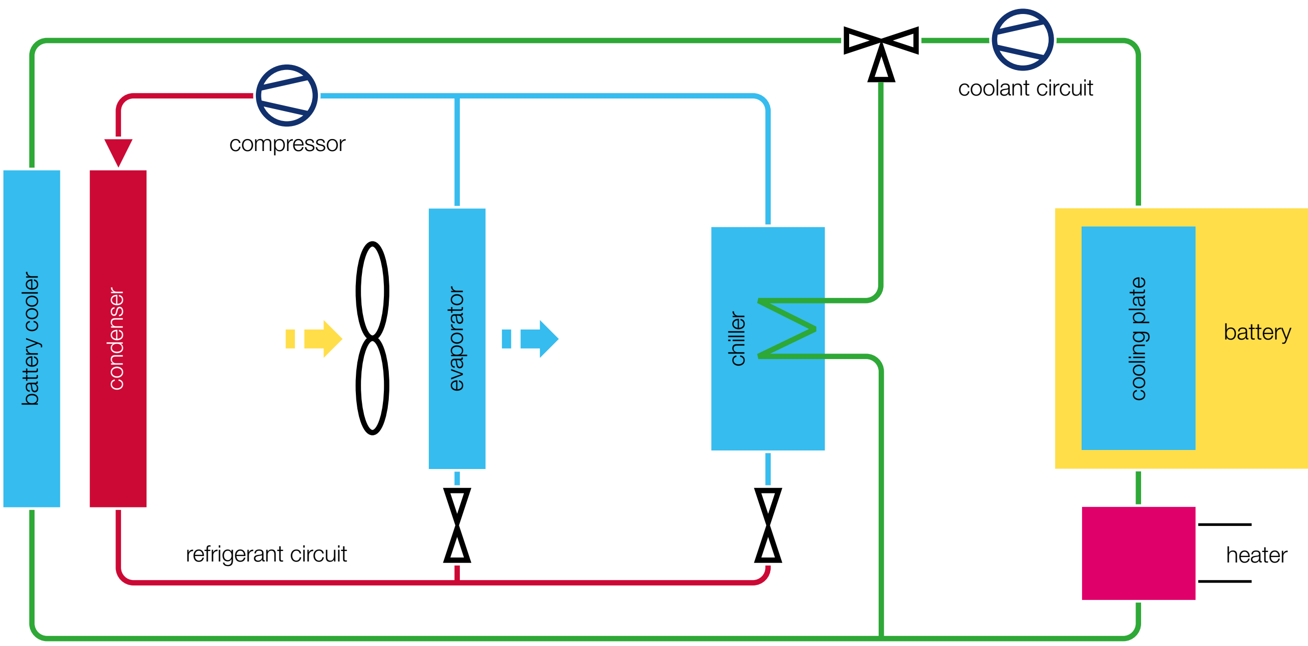
Coolant, made of water and glycol (green circuit), flows through a cooling plate integrated into the battery core. At lower temperatures, the coolant can be quickly heated by a heater to reach the ideal temperature. The heater is switched off if the temperature in the battery rises when the hybrid functions are being used. The coolant can then be cooled via a battery cooler located in the vehicle front using the airstream from the vehicle driving forward.

If the cooling by the battery cooler is not sufficient at high outside temperatures, the coolant flows through a chiller or special heat exchanger. In it, refrigerant from the vehicle air conditioning system is evaporated. In addition, heat can be transferred from the secondary circuit to the evaporating refrigerant in a very compact space and with a high power density. An additional recooling of the coolant is performed. Thanks to the use of the chiller, the battery can be operated within the most efficient temperature window.



Cooling module for hybrid vehicle

Coolant- and refrigerant-based circuit (or indirect battery cooling)



PTC auxiliary heaters

Thanks to the high efficiency of modern direct-injection engines, both diesel and gasoline, the engine waste heat is often not sufficient to quickly heat up the cabin on cold days nor to produce comfortable temperatures during urban driving and in stop-and-go traffic. Driving safety is also impaired, as the windows can fog up. To cover the shortfall in heating capacity, MAHLE is developing three types of auxiliary heater: electric PTC auxiliary heaters and CO_2 heat pumps for spontaneous heating of the supply air and exhaust gas heat exchangers for faster heating of the coolant. The coolant heating increases the performance and spontaneity of the conventional heating system and also shortens the engine's cold start phase. The heat pumps operate using the new CO_2 air conditioning system. With the auxiliary heaters mentioned, national and international standards can be met without any problems. PTC elements are nonlinear ceramic resistors. PTC stands for positive temperature coefficient, which means that the electrical resistance increases with the temperature of the element. However, this is not exactly true, because at first it drops as the temperature rises. The resistance characteristic curve has a negative temperature characteristic in this range. The negative temperature characteristic changes to a positive one only when the minimum resistance is reached. This means that as the temperature continues to rise, the resistance first drops slowly, then increases sharply from around 80°C until the PTC brick absorbs practically no additional current. At this point, when no air is flowing through the PTC heater, the surface temperature of the PTC brick is about 150°C and that of the metal frame approximately 110°C.

Design and function

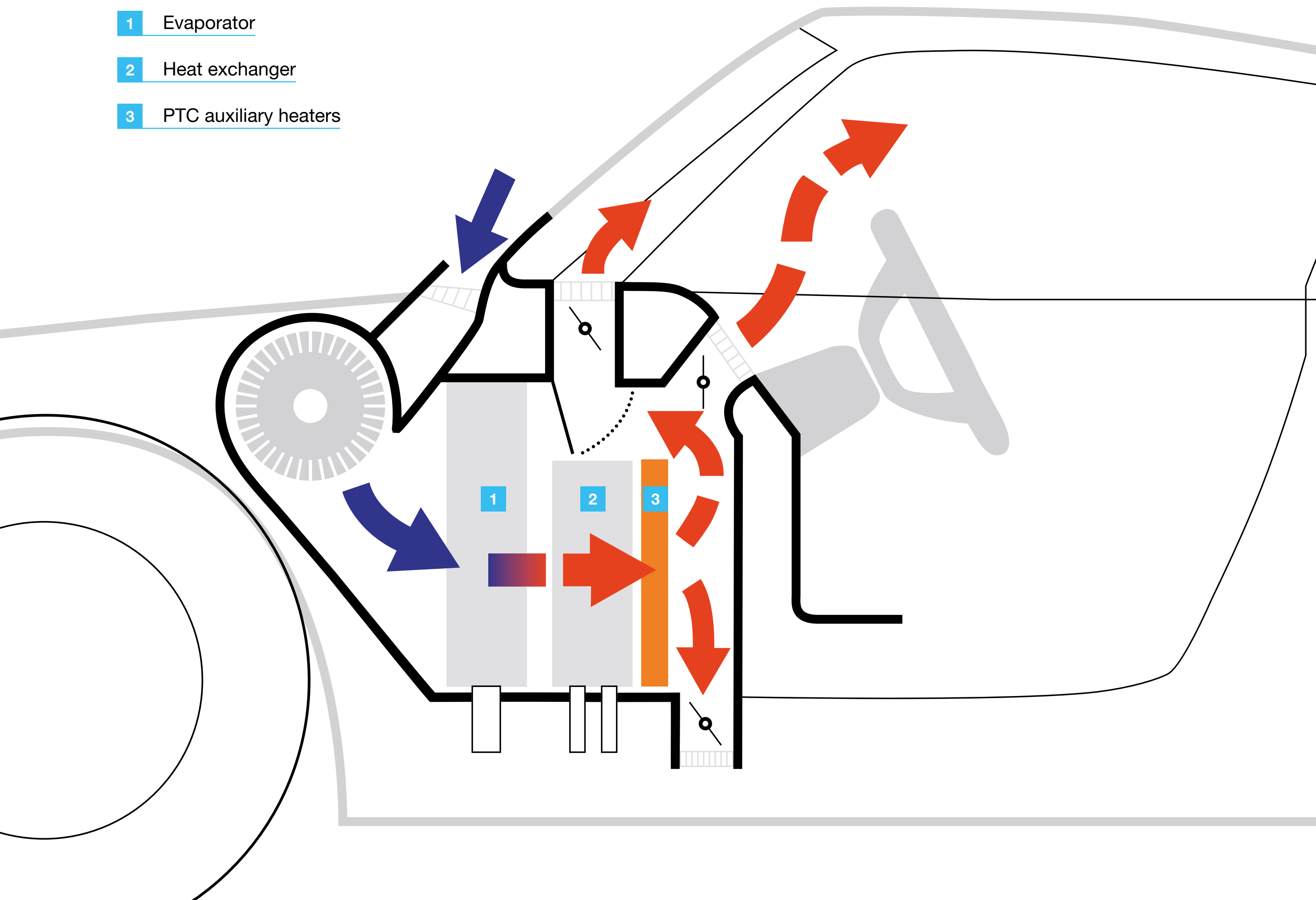
The PTC heater consists of several heating elements, a mounting frame, an insulating frame, and the relays or power electronics. The heating elements are composed of PTC ceramic bricks, contact sheets, terminals, and aluminum corrugated fins. The corrugated fins increase the heat-emitting surface of the contact sheets. To increase the air-side heat transfer, the fins have slits known as "gills." Thanks to the improved heat transfer, the excessive increase in cut-in current can be significantly reduced in comparison with auxiliary heaters featuring fins without gills. This has the advantage that individual PTC strands can be switched on more frequently—i.e., the heater can be operated with a higher overall output. The production know-how for these gills comes from radiator production. The auxiliary heater is located in the air conditioning system in the airflow directly behind the conventional heat exchanger, a coolant–air heat exchanger. This keeps the package requirements to a minimum. When outside temperatures are low and the engine is cold, only cold air, or air slightly heated by the heat exchanger, flows through the PTC heater initially. The temperature and resistance of the heating elements are low, but the heating performance is high. When the conventional heater responds, the air temperature and resistance increase and the heating performance decreases accordingly. At the surface temperature of a PTC heater, with warm 25°C air flowing through it, a volume flow of 480 kg of air per hour is achieved. The heating network reaches a mean temperature of 50°C at this air temperature.

Performance and spontaneity

A different nominal resistance can be selected for the PTC brick, which will alter the current consumption and performance accordingly. A low nominal resistance allows a high heating performance during operation. The output of a PTC heater is between 1 and 2 kW. At 2 kW, the power limit of the 12 V network (150 A at 13 V) is reached. Higher outputs would be possible with a 42 V electrical system. Because of its low mass and the fact that the electrically generated heat is transferred directly to the airflow without any detours, the PTC heater responds almost immediately. This high spontaneity is the characteristic feature of the PTC auxiliary heater. As the engine reaches operating temperature more quickly as a result of the additional load on the generator, the conventional heater also responds more quickly. This additional heating capacity is around two-thirds of the capacity of the PTC heater. In practice, this heating capacity can be assigned to the PTC heater. The output of the PTC heater of the 220 CDI E-Class model is 1.6 kW. The PTC heater is integrated in the heating and air conditioning module directly downstream of the conventional heat exchanger.

Test example

The vehicle was cooled down to an oil sump temperature of –20°C overnight. It was then driven in the climatic wind tunnel for 30 minutes in third gear at a speed of 32 km/h, which is a realistic average speed for urban traffic. After 20 minutes, the mean temperature in the cabin with a PTC heater reached 18°C; without it, the temperature only reached 10°C. With a PTC heater, the “comfortable temperature” of 24°C was reached after 30 minutes; without it, it took over 50 minutes to reach this temperature.



Operational safety

The characteristic resistance curve of the PTC bricks prevents the PTC heater from overheating. The temperature on the surface of the metal frame is always below 110°C. In addition, the output of the PTC heater is reduced at the higher discharge temperatures reached by the heat exchanger. Power electronics allow the PTC heater to be controlled in several stages or in a continuously variable manner, so that it can be adapted to the required heating performance or the available electrical output.

Control

The PTC heater is controlled either externally with relays or by means of an integrated control system with power electronics. With relay control, the vehicle manufacturer determines which and how many stages are switched on. The control system integrated in the auxiliary heater distinguishes between minimum and high functionality. At minimum functionality, the stages are switched on individually. The power electronics protect the auxiliary heater from overvoltage, short circuit, and reverse polarity. No diagnostics functionality is provided with this control system. Up to eight stages are possible with stepped control. The PTC auxiliary heater used in the E-Class has seven stages. The control is dependent on the power balance and auxiliary heating requirements—i.e., the desired thermal comfort. In the case of high-functionality control, the power electronics are controlled steplessly, for example, via the vehicle's LIN or CAN bus.

This means that the electricity provided by the electrical system in every situation can always be optimally utilized for auxiliary heating. In addition to protection against overvoltage, short circuit, and reverse polarity, the power electronics with high functionality include overload protection for each stage, protection of the printed circuit board against overheating, and voltage monitoring. The high-functionality control system can be diagnosed by means of an EPROM and thus allows variants to be stored (EPROM = erasable programmable read-only memory).

New developments

The new generation of PTC auxiliary heaters differs from the previous ones in that they are lighter, have a lower pressure drop (reduces the blower capacity), and lower manufacturing costs.

Technical characteristics:

- Electric auxiliary heater; output 1–2 kW
- Heat source: self-regulating PTC ceramic bricks, max. temperature on the surface of the ceramic 150°C when no air is flowing through the heating network
- Excellent heat transfer thanks to corrugated fin technology with low pressure drop in the supply air
- Stepped or linear control via relay or control electronics
- High spontaneity and high efficiency
- Modular design allows optimal adaptation to the available installation space in the vehicle
- Absolutely safe to operate, no danger to adjacent components because of inherent temperature limitation (PTC characteristic)
- Only small increase in required blower capacity due to low pressure loss

Diagnostics, maintenance, and repair

Used/new coolant

Coolant, antifreeze, and corrosion protection

Coolant is the generic term for the cooling fluid in the cooling system. Coolant protects against frost, rust, and overheating, while providing lubrication. Its task is to absorb the engine heat and dissipate it via the cooler.

The coolant is a combination of water and antifreeze (glycol/ethanol), mixed with various additives (bitter substances, silicate, antioxidants, foam inhibitors) and colored. The bitter substances are added to prevent the coolant from being drunk accidentally. Silicates form a protective coating on the metal surfaces and prevent limescale deposits, among other things. Antioxidants prevent components from becoming corroded. Foam inhibitors stop the coolant from foaming. Glycol keeps hoses and seals supple and raises the boiling point of the coolant.

The mixing proportion of water to antifreeze should be 60:40 to 50:50. This usually corresponds to antifreeze protection from –25°C to –40°C. The minimum mixing proportion should be 70:30 and the maximum mixing proportion 40:60. Further increasing the antifreeze proportion (e.g., 30:70) does not lower the freezing point anymore. In contrast, undiluted antifreeze already freezes at around –13°C and does not dissipate sufficient engine heat at temperatures above 0°C. This would cause the engine to overheat. Since glycol has a very high boiling point, the boiling point of the coolant can be increased to as high as 135°C by using the correct mixing proportion. This is why a sufficient amount of antifreeze is important even in warm countries. The manufacturer's recommendation should always be followed, a typical composition could be 40%/60% or 50%/50% with the use of inhibited water (drinking water quality).

The coolant and additives are subject to a certain degree of wear, so a portion of the additives will be used up over time. If, for example, the corrosion protection additives are used up, the coolant will turn brown. For this reason, some vehicle manufacturers prescribe a coolant replacement interval. However, the cooling systems of newer vehicles are increasingly filled with long-life coolants (e.g., VW G12++/G13). Under normal circumstances (if there is no contamination), no coolant changes are needed (VW) or are only necessary after 15 years or 250,000 km (newer Mercedes models). In general, the coolant should be changed in case of contamination (oil, corrosion) and in vehicles not filled with long-life coolants. It is essential to follow the vehicle manufacturer's instructions with regard to the specifications, replacement interval, mixing proportion, and miscibility of the antifreeze.

Coolant must not get into the groundwater or be discharged via the oil separator. It must be collected and disposed of separately.

Radiator maintenance

Cleaning with the steam jet at low pressure (from inside to outside) is an option, as with condensers. Reduced compressed air can also be used for external cleaning.

Flushing the cooling system

If the coolant is contaminated, the coolant must be drained and the cooling system flushed.

Contamination may include:

- Oil (defective cylinder head gasket)
- Rust (internal engine corrosion)
- Aluminum (internal radiator corrosion)
- Foreign matter (additives/sealing agents)
- Foreign particles (defective coolant pump)

Depending on the contamination level, the cooling system should be cleaned with warm water or with a special flushing agent. Depending on the vehicle manufacturer and symptom, there are various procedures for flushing. For example, in the event of rust-brown discoloration of the coolant and heating performance issues, Audi prescribes flushing with a special flushing agent. If multiple flushing processes are carried out, the thermostat must be removed and the heating performance measured before and after flushing. Opel advises—e.g., for the Corsa B, Vectra B, and Omega B models up to model year 1997—that a clogged radiator may be the cause of an excessively high engine temperature. In this case, flushing with warm water (>50°C) is recommended and all parts carrying coolant (heat exchanger, cylinder head, etc.) should be replaced in addition to the radiator. The degree of contamination and the vehicle manufacturer's specifications thus determine the process and the flushing medium to be used. In any case, it is important to note that, because of their design (e.g., flat tube), not all components of modern cooling systems can be flushed and therefore will need to be replaced.

This applies in particular to the following components:

- Thermostat
- Radiator
- Electric valves
- Filler cap
- Heat exchanger

If the coolant level in the expansion tank is no longer visible because of contamination (oil, rust), the tank must also be replaced. The thermostat and the filler cap should always be replaced. When using special cooling system cleaners, care must be taken to ensure that these do not attack sealing materials or get into the groundwater and are not discharged via the oil separator. The cleaning agents must be collected together with the coolant and disposed of separately. After flushing, the system must be refilled with coolant (observe specification and mixing proportion) according to the vehicle manufacturer's specifications, bled, and checked for function and leaktightness.

Bleeding the system during filling

Entrapped air in the cooling system of motor vehicles is now a widespread problem. These “bubbles” are caused by the radiator or expansion tank being positioned at the same level as the engine or even below it. Therefore, completely bleeding the cooling system after a repair or when replacing the coolant can be a serious problem. Any air remaining in the cooling system significantly reduces the circulation of the coolant and can lead to overheating of the engine and result in major damage. This can be remedied with a special filling and bleeding tool.

This allows you to carry out the following tasks:

- Eliminate bubbles
- Check for leaks
- Perform a quick refill of the cooling system

The Airlift is connected to the cooler or expansion tank by means of the supplied adapter. You then connect a compressed-air hose, which you normally use to operate your compressed-air tool. The cooling system is now evacuated via a special valve and a high negative pressure is generated. Then the supplied suction hose is connected and the fresh water–antifreeze mixture is topped up using a clean coolant container (bucket, can). With the help of the manometer, which measures the negative pressure on the Airlift, the leaktightness of the whole system can be checked at the same time.

Checking the cooling system by means of a pressure and pressure drop test

The use of a pressure tester is recommended to check the cooling system for leaks. The cooling system is pressurized by means of a hand pump. By observing the pressure gauge, a leak in the cooling system can be detected in the event of a pressure drop. Using universal or vehicle-specific adapters, the pump can be adapted to almost all standard commercial vehicles, passenger cars, and agricultural and construction machinery via a quick lock. For leaks that are difficult to detect, the cooling system can be filled in advance with a contrast medium.

Typical damage

The pictures show typical damage caused by various factors.

Radiator

All faults cause reduced radiator performance. Repairs are not common in modern radiators, as aluminum welding is quite difficult and could lead to blockages in the small ducts. Sealant must not be used because it can cause blockages and reduce performance.

Cabin heat exchangers

Limescale deposits and the use of sealants can lead to blockages in the cabin heat exchanger, as in the radiator. In some cases, these can be removed by flushing with certain cleaning agents. The vehicle manufacturer's instructions should be followed.

Corrosion due to incorrect or stale coolant

Limescale deposits as a result of using pure water (without coolant)

Calcified heat exchanger

Cooling system testing and diagnostics

In the event of a malfunction in the cooling system—e.g., insufficient heating performance, the engine does not reach operating temperature, or the system overheats—investigating the cause of the fault is straightforward. First, the cooling system should be checked for sufficient coolant level, contamination, antifreeze, and leaks. Also ensure that the V-belt or V-ribbed belt is sufficiently tensioned.

Then, depending on the symptoms, the troubleshooting can be continued as follows by observing components or measuring temperatures:

Engine overheats:

- **Is the displayed temperature realistic?**
  (Check coolant temperature sensor and display instrument if necessary)
- **Are the radiator and upstream components (air conditioning condenser) free from contamination, in order to ensure an unrestricted flow of air?**
  (Clean components if necessary)
- **Are the radiator fan and auxiliary fan working?**
  (Check switch-on point, fuse, thermal switch, and fan control unit, check for mechanical damage)
- **Does the thermostat open?**
  (Measure temperature in front of and behind the thermostat; if necessary, remove thermostat and check in water bath)
- **Is the radiator clogged?**
  (Check temperature at inlet and outlet of the radiator, check flow rate)
- **Is the coolant pump working?**
  (Check that the pump wheel is not loose on the drive shaft)
- **Are the pressure-relief and vacuum valves of the radiator filler cap and expansion tank working?**
  (Use test pump if necessary, check if seal of cap is damaged or present)

Engine does not heat up:

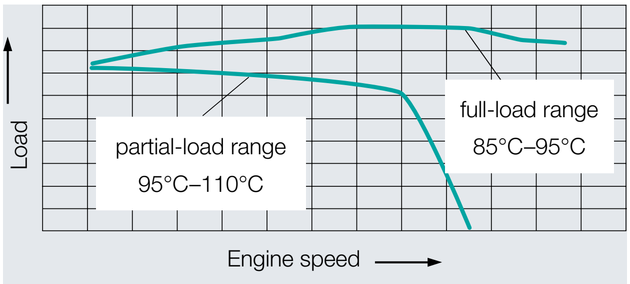
- **Is the displayed temperature realistic?**
  (Check coolant temperature sensor and display instrument if necessary)
- **Is the thermostat permanently open?**
  (Measure temperature in front of and behind the thermostat;
  if necessary, remove thermostat and check in water bath)
- **Is the radiator fan or auxiliary fan permanently running?**
  (Check switch-on point, thermal switch, fan control unit)

Heater does not heat up sufficiently:

- **Does the engine reach operating temperature and does the coolant heat up?**
  (If necessary, first carry out the test steps under “Engine does not heat up”)
- **Does the heater valve open?**
  (Check electric actuation or bowden cable and valve)
- **Is the heater cooler (cabin heat exchanger) clogged?**
  (Check temperature at inlet and outlet of the heat exchanger, check flow rate)
- **Is the flap control working properly?**
  (Check door settings and stops, fresh air–recirculated air function, air outlet nozzles)
- **Is the interior blower working?**
  (Noises, fan levels)
- **Is the cabin filter clogged or is the airflow insufficient?**
  (Check cabin filter, ventilation ducts for air infiltration)

Electronically controlled cooling*

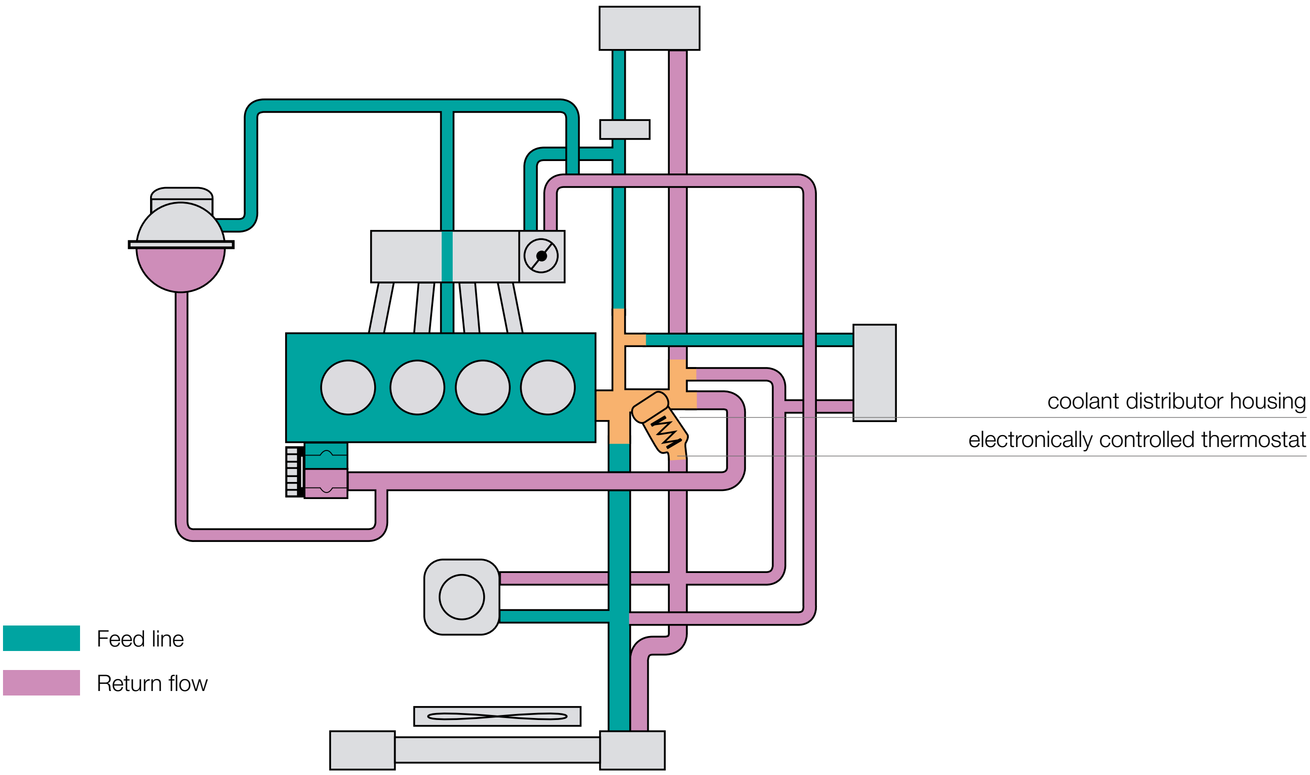
(Example: VW 1.6/APF engine)



Coolant temperature level

The performance of the engine depends on correct cooling. With thermostat-controlled cooling, the coolant temperatures range from 95°C to 110°C in the partial-load range and from 85°C to 95°C in the full-load range. Higher temperatures in the partial-load range result in a more favorable performance level, which has a positive effect on consumption and pollutants in the exhaust gas. Lower temperatures in the full-load range increase the output. The intake air is heated less, which leads to an increase in performance.

Overview of electronically controlled cooling system



* From VW Audi/Self-study program 222/Electronically controlled cooling system

The development of an electronically controlled cooling system was aimed at regulating the operating temperature of the engine to a set point depending on the load case. An optimal operating temperature is regulated by the electrically heated thermostat and the radiator fan levels, according to operating maps stored in the engine control unit. In this way, the cooling can be adjusted throughout the power and load spectrum of the engine.

The advantages of adjusting the coolant temperature to the current operating condition of the engine are:

- Reduction of fuel consumption in partial-load range
- Reduction in CO and HC emissions

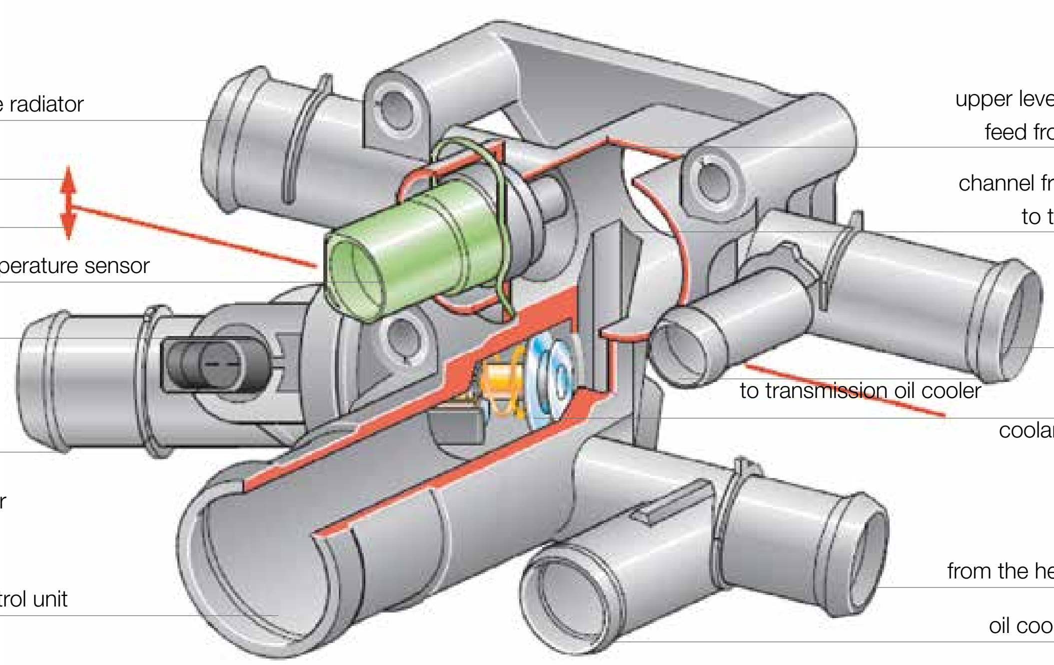
Differences compared with a conventional cooling circuit:

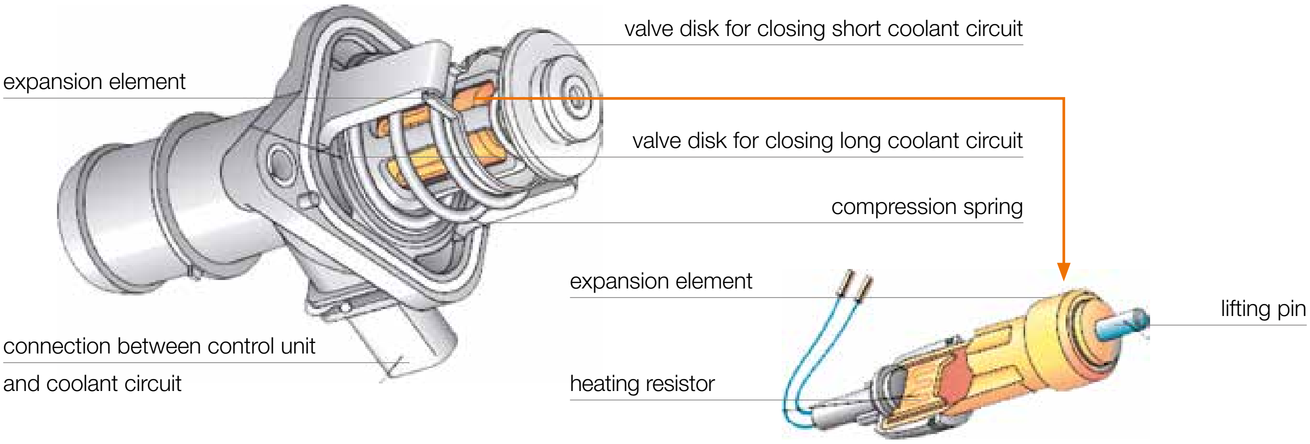
- Integration in the cooling circuit thanks to minimal design changes
- Coolant distributor housing and thermostat form a single unit
- Coolant regulator (thermostat) not required in the engine block
- Engine control unit additionally contains the operating maps of the electronically controlled cooling system

Coolant distributor housing

The coolant distributor housing is mounted directly on the cylinder head instead of the connecting socket. It should be viewed on two levels. The individual components are supplied with coolant from the upper level, the infeed to the coolant pump being an exception. The coolant return from the individual components is connected in the lower level of the distributor housing. A vertical channel connects the upper and lower levels.

The thermostat opens/closes the vertical channel with its small valve disk. The coolant distributor housing is effectively a station that distributes the coolant to the large or small cooling circuit.





Coolant control unit

Functional components

- Expansion thermostat (with wax element)
- Resistance heating in the wax element
- Compression springs for mechanical closing of the coolant channels, 1 large and 1 small valve disk

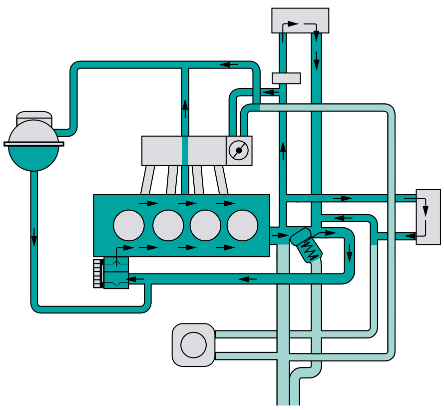
Function

The expansion thermostat in the coolant distributor housing is constantly surrounded by coolant. The wax element controls without heating as before, but is designed for a different temperature. Above the coolant temperature, the wax becomes liquid and expands.

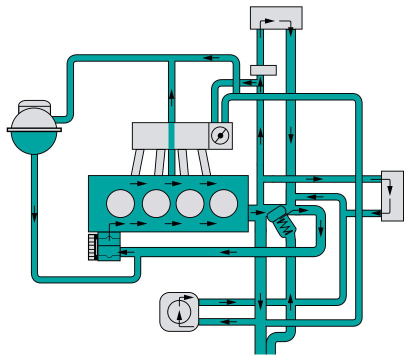
This expansion causes the lifting pin to lift. Under normal conditions (without current), this occurs according to the new temperature profile of 110°C coolant temperature at the engine outlet. A heating resistor is embedded in the wax element. If this resistor is supplied with current, it also heats the wax element, and the lift or adjustment is now not only dependent on the coolant temperature but also takes place as specified by the engine control unit according to the operating map.

Long and short coolant circuit

As with the previous circuits, there are two circuits that are controlled in this case. The short circuit serves to warm up the engine quickly during an engine cold start and under partial load. The map-controlled engine cooling does not take effect yet. The thermostat in the coolant distributor housing has blocked the return flow from the radiator and opened up the short path to the coolant pump. The radiator is not integrated into the coolant circulation.



The long coolant circuit is opened either by the thermostat in the coolant regulator after reaching approx. 110°C or by the operating map, depending on the load. The radiator is now included in the coolant circuit. To support cooling by the airstream or when idling, electrically driven fans are switched on as required.



Electronic control: overview

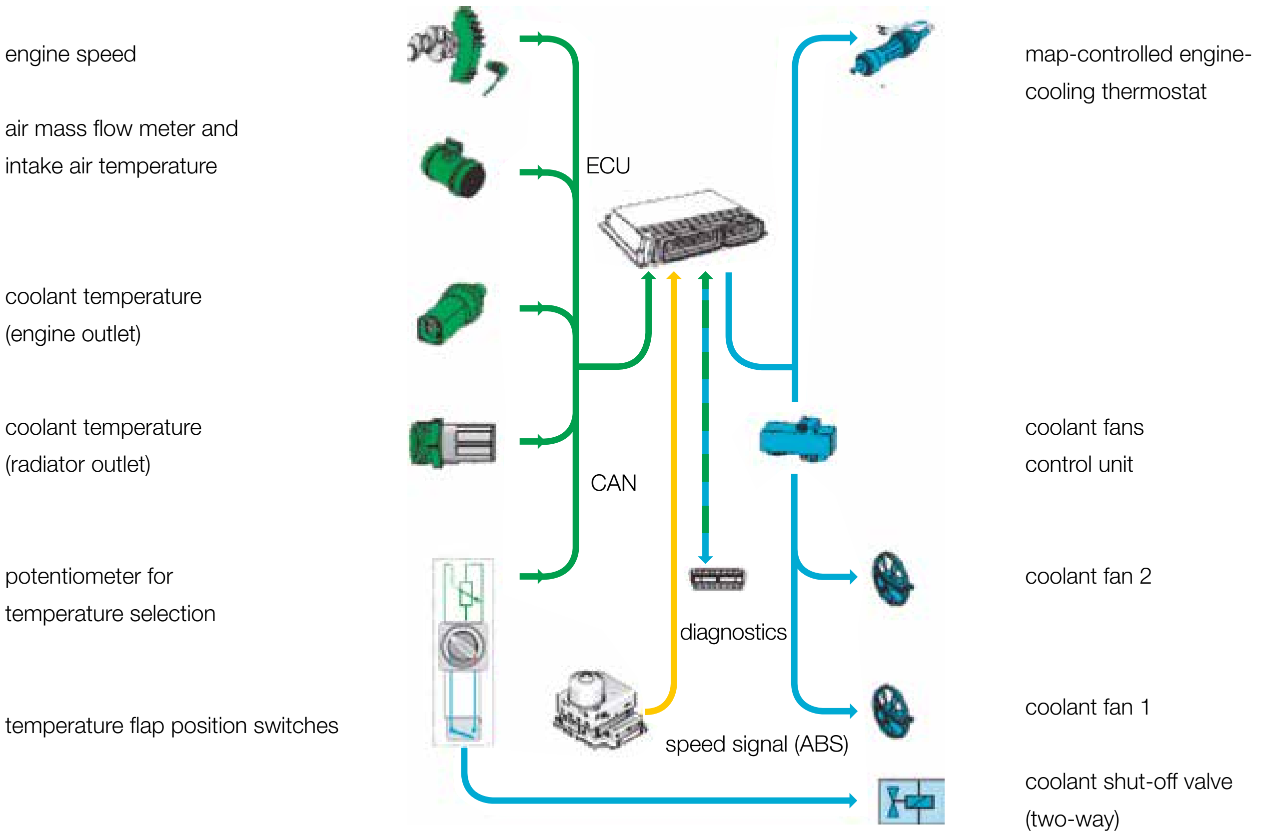
The engine control unit has been extended to include the connections for the sensors and actuators of the electronically controlled cooling system:

- Thermostat power supply (output)
- Radiator return flow temperature (input)
- Radiator fan control (two outputs)
- Potentiometer on heating controller (input)

The operating map temperature functions are calculated every second. The system control is initiated as a result of the function calculations:

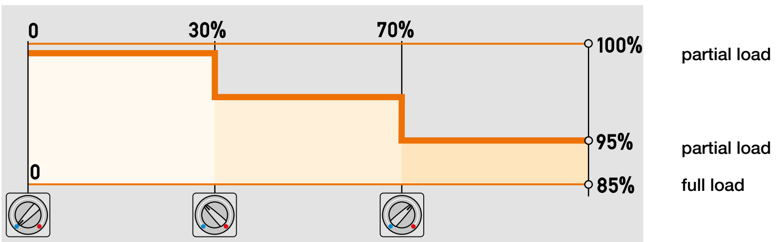
- Activation (power supply) of the heating resistor in the thermostat for map-controlled engine cooling to open the long cooling circuit (regulation of the coolant temperature)
- Control of radiator fans to support the rapid reduction in coolant temperature

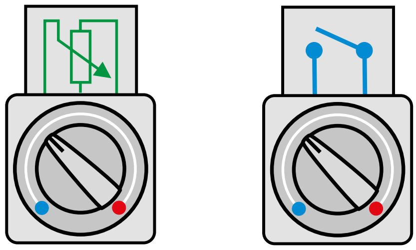
For any other necessary information, the sensors of the engine control system are used.



Regulation of the coolant temperature when heating is required

The coolant temperature can oscillate between 110°C and 85°C when driving between partial load and full load. A temperature difference of 25°C would feel unpleasant in the cabin of the vehicle when the heating is switched on. The driver would have to readjust constantly. By means of the potentiometer, the electronics in the cooling system detect the driver's heating requirements and regulate the coolant temperature accordingly—e.g., from rotary knob position 70% = 95°C coolant temperature. A microswitch on the rotary knob for temperature selection opens as soon as the knob is no longer set to the "heating off" position. This activates a pneumatic two-way valve, which in turn uses negative pressure to open the coolant shut-off valve for the heat exchanger.





Potentiometer

Microswitch

Operating map—set points

The control of the thermostat for map-controlled engine cooling (large or small cooling circuit) is regulated by operating maps. The relevant temperature set points are stored in these maps. The engine load is the decisive factor. The load (air mass) and speed determine the coolant temperature to be set.

Temperature set points are stored in a second operating map, depending on speed and intake air temperature. This determines in the coolant temperature to be set. Comparing operating maps 1 and 2, the lower value is used as the set point and the thermostat is adjusted accordingly. The thermostat only becomes active when a temperature threshold has been exceeded and the coolant temperature is just below the set point.

Coolant temperature sensor

The temperature sensors work as NTC resistors. The coolant temperature set points are stored in the engine control unit as operating maps. The actual coolant temperature values are taken at two different points in the cooling circuit and transmitted to the control unit as voltage signals.

Actual coolant value 1—directly at the coolant outlet on the engine in the coolant distributor.

Actual coolant value 2—on the radiator before the coolant exits the radiator.

Signal usage: The comparison between the setpoint temperatures stored in the operating maps with actual temperature 1 determines the duty cycle for supplying current to the heating resistor in the thermostat. The comparison between actual coolant values 1 and 2 forms the basis for controlling the electric fans for coolant.

Substitute function: If the coolant temperature sensor (engine outlet) fails, coolant temperature control continues with a fixed substitute value of 95°C, with fan level 1 permanently activated.

If the coolant temperature sensor (radiator outlet) fails, the control remains active and fan level 1 is permanently activated. If a certain temperature threshold is exceeded, fan level 2 is activated. If both sensors fail, maximum voltage is applied to the heating resistor and fan level 2 is permanently activated.

Coolant temperature sensor

Map-controlled thermostat

A heating resistor is embedded in the wax element of the expansion thermostat. This additionally heats the wax, which expands and generates the lift “x” of the lifting pin according to the operating map. The mechanical adjustment of the thermostat is determined by the lift “x.” The heating is controlled by the engine control unit according to the operating map via a PWM (pulse width modulation) signal. The heating output varies as a function of the pulse width and time.

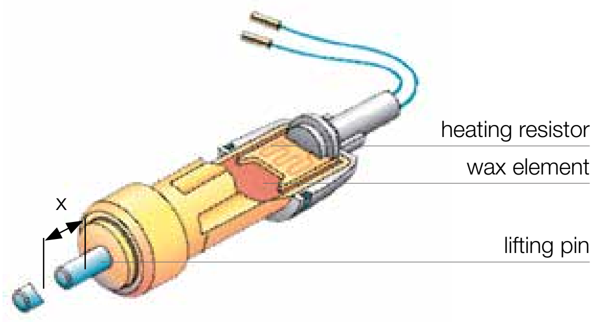
Rule:

- PWM low (no voltage) = high coolant temperature
- PWM high (with voltage) = low coolant temperature

No operating voltage:

- Control only using expansion element
- Fan level 1 is permanently activated

The thermostat heater is not used to heat up the coolant—it heats the thermostat selectively or controls it in order to open the large coolant circuit. No voltage is applied when the engine is stopped or started.



Wax expansion element

Summary

Modern cooling systems have become much more technical—like all other systems found in automobiles today. Basic knowledge is no longer sufficient to understand and diagnose modern thermal management systems. You need systems expertise, technical documentation, and the ability to think logically.

In the past there was engine cooling; now, there's thermal management

Thermal management components

Technical information

Radiator

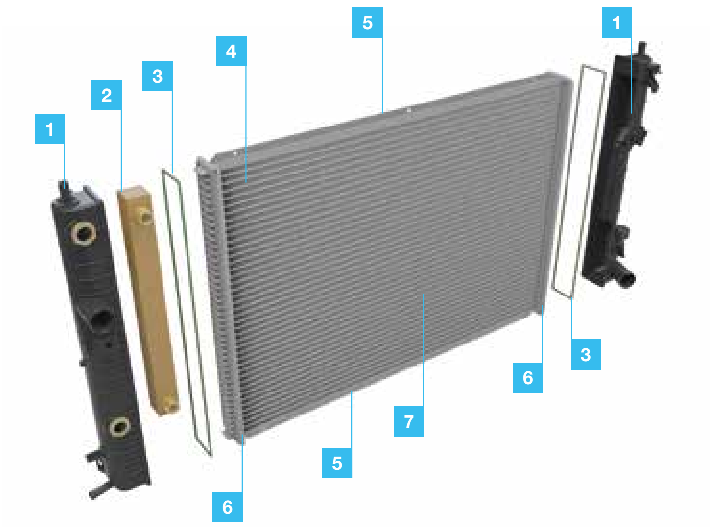
General

Radiators are installed in the airflow of the vehicle front and differ in terms of their design. Their task is to release the heat generated by combustion in the engine, which is absorbed by the coolant, to the outside air. Other coolers—e.g., for automatic transmissions—can be found in or on the radiator.

Radiator

Design/function

The most important component of the cooling module is the radiator (RAD), which consists of the radiator core and water tanks with all requisite connections and fastening elements. The radiator core itself is made up of the core matrix—a fin-and-tube system—the tube headers, and the core covers. Conventional radiators have a coolant tank made of glass fiber-reinforced polyamide, which is sealed and beaded before being placed on the tube header. The current trend is toward all-aluminum radiators, which are characterized by less weight and a low installation depth. They're also 100% recyclable. The coolant is cooled down via the cooling fins (core matrix). The outside air flowing through the radiator's core matrix extracts heat from the coolant. In terms of design, a distinction is made between downdraft and crossflow radiators. In a downdraft radiator the water enters at the top of the radiator and exits at the bottom. In a crossflow radiator, the coolant enters on one side of the radiator and exits on the other side. If the inlet and outlet of the crossflow radiator are on the same side, the water tank is divided. The coolant then flows through the upper and lower part of the radiator in opposite directions. Crossflow coolers are designed to be positioned lower and are most commonly used in passenger cars.



1 Water tank

2 Oil cooler

3 Seals

4 Cooling fins (core matrix)

5 Side plates

6 Base

7 Cooling tube

Impact in the event of failure

The following symptoms may indicate a defective radiator:

- Poor cooling performance
- Increased engine temperature
- Radiator fan running continuously
- Poor air conditioning system performance

Possible causes may include:

- Coolant loss due to radiator damage (stone chip, accident)
- Coolant loss due to corrosion or leaky connections
- Poor heat exchange due to external or internal contamination (dirt, insects, limescale deposits)
- Contaminated or stale cooling water

Limescale deposits in the radiator

Troubleshooting

Test steps to detect the defect:

- Check radiator for external contamination, clean with reduced compressed air or a water jet if necessary—do not get too close to the cooler fins
- Check radiator for external damage and leaks (hose connections, flanges, fins, plastic housing)
- Check coolant for discoloration/contamination (e.g., oil due to defective head gasket) and antifreeze content
- Check coolant flow (clogging with foreign materials, sealant, limescale deposits)
- Measuring the coolant inlet and outlet temperature using an infrared thermometer

Corrosion deposits in the radiator

Radiator filler cap

General

It is often overlooked, but important: the radiator filler cap. In addition to sealing the filling opening in the radiator or expansion tank so that it is gastight, it ensures that there is no negative pressure or excessive overpressure in the cooling system. For this purpose, the filler cap is equipped with a vacuum valve and a pressure-relief valve. The pressure-relief valve serves to increase the pressure by approx. 0.3 to 1.4 bar. As a function of this value, the boiling temperature of the coolant increases to 104°C–110°C, improving the performance of the cooling system. In hermetically sealed systems, a vacuum would be created during cooling. Preventing this is the task of the vacuum valve.

Metal filler cap

Plastic filler cap

Design/function

A high coolant temperature leads to a pressure increase in the cooling system as the coolant expands. The coolant is forced into the tank. The pressure in the tank increases. The pressure-relief valve in the cap opens and allows air to escape. When the coolant temperature normalizes, a vacuum is created in the cooling system. Coolant is sucked out of the tank, which creates a vacuum in the tank. As a result, the vacuum compensation valve in the filler cap of the tank opens. Air flows into the tank until the pressure equalizes.

Expansion tank

Guidelines for opening the radiator filler cap:

- Allow the cooling system to cool to a coolant temperature below 90°C.
- The cooling system is under pressure when the engine is warm.
- There is a risk of scalding if the cooling system is opened suddenly!
- Open the coolant filler cap up to the pre-stop, with an additional half-turn for screwed variants, and release the overpressure.
- Wear protective gloves and goggles as well as protective clothing!

Filler cap with test adapter

Manometer for pressure testing

Functional test:

- The valve of the radiator filler cap can be tested for proper functioning using a suitable testing device (according to the vehicle manufacturer's specifications).
  1. Determine opening pressure by increasing pressure.
  2. The vacuum valve must lie against the rubber sealing, be easily lifted, and spring back after release.
- MAHLE recommends replacing the filler cap each time the radiator is replaced.

Metal filler cap with pressure-relief valve

Flushing the cooling system

If the cooling system is contaminated, the coolant must be drained and the cooling system flushed.

Contamination may include:

- Oil (defective cylinder head gasket)
- Rust (internal engine corrosion)
- Aluminum (internal radiator corrosion)
- Foreign matter (additives/sealing agents)
- Foreign particles (defective coolant pump)

Tests on faulty radiators have shown that rust sludge is the most frequent cause of contamination. It is due to a lack of or insufficient cleaning during a repair to the cooling system, by using the wrong antifreeze, or by reusing drained coolant. Rust sludge can settle and clog narrow channels, acts as a corrosion accelerator when bare metal surfaces are covered with it (anodic effect with pitting corrosion), and acts as an abrasive in the coolant circuit, especially in places where the flow direction is reversed.

Cleaning

Depending on the contamination level, the cooling system should be cleaned with warm water or with a special flushing agent. Depending on the vehicle manufacturer and symptom, there are various procedures for flushing. For example, in the event of rust-brown discoloration of the coolant and heating performance issues—e.g., in the A6—Audi prescribes flushing with a special flushing agent. If multiple flushing processes are carried out, the thermostat must be removed and the heating performance measured before and after flushing.

Volkswagen prescribes a cleaning agent with de-oiling effect and the following procedure:

- Bring the engine up to operating temperature.
- Drain the coolant.
- For 4-cylinder engines, fill with 3 liters of cleaning agent and add water.
- For 8-cylinder engines, fill with 4 liters of cleaning agent and add water.
- Run the engine for 20 minutes with the thermostat open.
- Drain the cleaning agent.
- Repeat the process until the cleaning liquid runs clear.
- Repeat the procedure two more times with fresh water.
- Fill with antifreeze.

For various models, Opel advises that a clogged radiator may be the cause of an excessively high engine temperature. In this case, flushing with warm water (>50°C) is recommended and all parts carrying coolant (heat exchanger, cylinder head, etc.) should be replaced in addition to the radiator. Most cleaning agents are based on components of formic, oxalic, or hydrochloric acid, which must not remain in the cooling system. Rinse thoroughly!

Emulsion-like deposits in the heat exchanger with turbulence inserts

Sometimes leaks that were not visible before appear after cleaning. This is often thought to be due to aggressive cleaning agents. However, the actual cause here is a defect that has been present for some time, with the seal only being maintained by dirt deposits. MAHLE recommends cleaning before installing any new component in the cooling circuit.

The degree of contamination and the vehicle manufacturer's specifications determine the process and the flushing medium to be used.

It is important to note that, because of their design (e.g., flat tube), not all components of modern cooling systems can be flushed and therefore will need to be replaced.

This applies in particular to the following components:

- Thermostat
- Radiator
- Electric valves
- Filler cap
- Cabin heat exchangers

If the coolant level in the expansion tank is no longer visible because of contamination (oil, rust), the tank must also be replaced.

The thermostat and the filler cap should always be replaced.

When using cooling system cleaners, care must be taken to ensure that these do not attack sealing materials or get into the groundwater and are not discharged via the oil separator. The cleaning agents must be collected together with the coolant and disposed of separately. After flushing, the system must be refilled with coolant (observe specification and mixing proportion) according to the vehicle manufacturer's specifications, bled, and checked for function and leaktightness.

Antifreeze = rust inhibitor!

Contaminated cooling system components

Coolant pumps

General

Coolant pumps are usually driven mechanically, via a timing belt or V-ribbed belt, and transport the coolant through the engine's coolant circuit. The pumps can be either flanged directly to the engine or separate to it. The designs vary considerably. Coolant pumps have to withstand enormous temperature fluctuations (–40°C to approx. +120°C). Changing speeds (500–8,000 rpm) and pressures of up to 3 bar require highly stable bearings and seals.

To save fuel, electrically driven and electronically controlled coolant pumps will become increasingly common in the future.

Coolant pump

Design/function

The mechanical coolant pump consists of the following five assemblies:

1. Housing

2. Drive wheel

3. Roller bearing

4. Mechanical seal

5. Impeller

The drive wheel and impeller are mounted on a common shaft. A mechanical seal seals the pump shaft from the outside. The rotating movement of the impeller transports the coolant through the cooling system. Impellers are usually made of plastic or metal. The bearing load is lower for plastic wheels. At the same time, they are less susceptible to cavitation.

However, plastic wheels occasionally become brittle with age. The mechanical sealing ring is always lubricated and cooled by the coolant. By design, small amounts of coolant can enter the free space behind the sealing ring and exit at the pump relief hole. Visible traces of coolant are by no means a clear indication of a defective pump.

Impact in the event of failure

The following symptoms may indicate a coolant pump failure:

- Noises
- Coolant loss
- Inadequate cooling/engine overheats

Possible causes may include:

- Mechanical damage:
  Impeller loose/broken
  Bearing or seal defective
  Drive wheel damaged
- Cross section narrowing due to corrosion or sealant
- Cavitation:
  Damage to the impeller due to formation and disintegration of vapor bubbles in the coolant
  Electrical fault (short circuit/interruption)

Troubleshooting

Coolant leakage at the pump caused by the following, for example:

- Excessive application of sealant: sealing material residues can enter the cooling circuit and damage the mechanical seal, for example.

Corrosion throughout the cooling system:

- Defective cylinder head gasket—engine exhaust gases enter the cooling system; negative change in pH value.

Pump parts such as impeller, housing, mechanical seal, and shaft heavily damaged by pitting corrosion:

- Stale/used coolant with a high chloride content (salt compounds) in conjunction with increased temperatures

Excessive coolant leakage at the relief hole:

- Caused by corrosion in the cooling system

Instructions for removal and installation

When replacing the coolant pump, the specifications of the product packaging insert and special installation instructions of the vehicle manufacturer must always be observed. If the cooling system is contaminated, it must be flushed. The cooling system should only be filled with a coolant that meets the vehicle manufacturer's specifications. The system must be filled or bled according to the vehicle manufacturer's instructions. Incorrect installation can lead to overheating of the engine, damage to the belt drive, and/or engine damage.

Information on the use, specifications, and replacement intervals of coolants can be found in the "Coolant" technical information.

Expansion tank

General

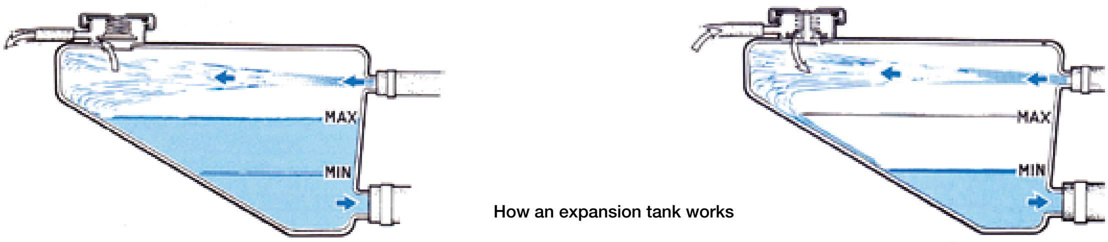
The expansion tank in the cooling system is usually made of plastic and is designed to hold the expanding coolant. It is usually installed in such a way that it represents the highest point in the cooling system. To allow the coolant level to be checked, it is transparent and has “Min” and “Max” markings. In addition, an electronic level sensor can also be installed. The pressure in the cooling system is equalized via the valve in the expansion tank filler cap.

Expansion tank

Design/function

An increase in the coolant temperature leads to a pressure increase in the cooling system as the coolant expands. This causes the pressure in the expansion tank to rise, which opens the pressure-relief valve in the filler cap and allows air to escape.

When the coolant temperature normalizes, a vacuum is created in the cooling system. Coolant is sucked back out of the tank, which also creates a vacuum in the tank. As a result, the vacuum compensation valve in the filler cap of the tank opens. Air flows into the tank until the pressure equalizes.



How an expansion tank works

Impact in the event of failure

The following symptoms may indicate a defective expansion tank or filler cap:

- Loss of coolant (leakage) at various system components or at the expansion tank itself
- Excessive coolant or engine temperature
- Expansion tank or other system components cracked/burst

Possible causes may include:

- Overpressure in the cooling system due to a faulty valve in the filler cap
- Material fatigue

Troubleshooting

Test steps to detect the defect:

- Check coolant level and antifreeze content.
- Check for discoloration/contamination (oil, sealant, limescale deposits) of the coolant.
- Check thermostat, cooler, heat exchanger, hose lines, and hose connections for leaks and function.
- If necessary, pressurize the cooling system (pressure test).
- Check for entrapped air in the cooling system; if necessary, bleed the cooling system according to the vehicle manufacturer's instructions.

If all the above steps have been carried out without finding any problems, the filler cap of the expansion tank should be replaced. Testing the filler cap valve is difficult.

Cabin heat exchangers

General

The heat exchanger is installed in the heating box of the vehicle cabin and the coolant flows through it. The air for the cabin flows through the heat exchanger and is heated in the process.

Heat exchanger

Design/function

The cabin heat exchanger, like the radiator, consists of a mechanically joined fin-and-tube system. Once again, the trend is toward an all-aluminum design. The coolant flows through the cabin heat exchanger. The flow rate is usually controlled by mechanically or electrically actuated valves. The cabin air is heated by the cooling fins (core matrix) of the heat exchanger. The airflow generated by the interior blower or airstream is directed through the cabin heat exchanger, through which hot coolant flows. This heats up the air, which then continues into the vehicle cabin.

Impact in the event of failure

The following symptoms may indicate a defective or poorly functioning cabin heat exchanger:

- Poor heating performance
- Coolant loss
- Odor (sweetish)
- Fogged windows
- Poor airflow rate

Possible causes may include:

- Poor heat exchange due to external or internal contamination (corrosion, coolant additives, dirt, limescale deposits)
- Coolant loss due to corrosion
- Coolant loss due to leaky connections
- Clogged cabin filter
- Contamination/blockage in ventilation system (leaves)
- Defective flap control

Troubleshooting

Test steps to detect the defect:

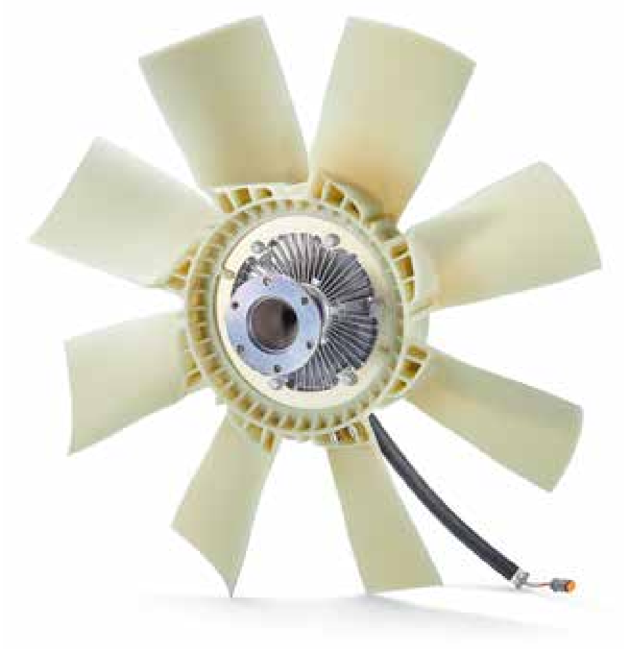
- Check for odors and window fogging.
- Check the cabin filter.
- Check cabin heat exchanger for leaks (hose connections, flanges, core matrix).
- Check for contamination/discoloration of the coolant.
- Check coolant flow (clogging with foreign matter, limescale deposits, corrosion).
- Measure coolant inlet and outlet temperature.
- Check for blockages/foreign matter in the ventilation system.
- Check flap control (recirculated air/fresh air)

All-aluminum heat exchanger

Visco® fans

General

In addition to high-performance radiators, fans and fan drives that can supply cooling air efficiently are also needed to dissipate heat from commercial vehicle and powerful passenger car engines. Visco® fans consist of a fan wheel and a Visco® clutch. They are used in longitudinally mounted engines, installed in front of the radiator (direction of travel), and driven via a V-belt or directly by the engine.



Visco® clutch with fan

Design/function

The fan wheel is usually made of plastic and is screwed to the Visco® clutch. The number and position of the fan blades vary depending on the design. The housing of the Visco® clutch is made of aluminum and features numerous cooling fins. The Visco® fan can be controlled by a purely temperature-dependent, self-regulating bimetal clutch. The process variable here is the ambient temperature of the radiator. Another variant is the electrically controlled Visco® clutch. This clutch is electronically controlled and electromagnetically actuated. The input variables of various sensors are used for control. Further details can be found in the technical information on the Visco® clutch.

Impact in the event of failure

The following symptoms may indicate a defective Visco® fan:

- Loud noise development
- Increased engine or coolant temperature

Possible causes may include:

- Damaged fan wheel
- Oil loss/leaks
- Contamination of the cooling surface or bimetal
- Bearing damage

Troubleshooting

Test steps to detect the defect:

- Check the coolant level.
- Check the fan wheel for damage.
- Check for oil leakage.
- Check bearings for play and noise.
- Check fastening of fan wheel and Visco® clutch.
- Check that the air guide plates/air scoop are properly secured and present.

Visco® clutch

Visco® clutch

General

The Visco® clutch is part of the Visco® fan. Its purpose is to create a temperature-dependent frictional connection between the drive and the fan wheel and to influence its speed. Attached to the clutch is a plastic fan, which generates the airflow as required. Visco® fans are mainly used in longitudinally mounted, large-displacement passenger cars and in commercial vehicles.

Design/function

The Visco® clutch is usually driven directly by the engine via a shaft (Figure 1). If no cooling air is needed, the Visco® clutch switches off and runs at a low speed. As demand increases, silicone oil flows from the reservoir to the working chamber. There, the drive torque is transferred wear-free via liquid friction to the fan, whose speed is variably adjusted to the operating conditions.

Figure 1

The switch-on point is approx. 80°C. In the conventional Visco® clutch, the radiator exhaust air encounters a bimetal (Figure 2) whose thermal deformation causes a valve to open and close via a pin and valve actuating lever. The transmittable torques and fan speeds depend on the valve position and thus the oil quantity in the working chamber. The oil filling quantity is 30–50 ml (passenger car).

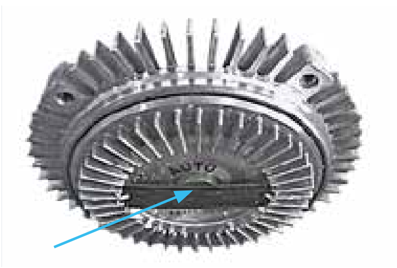


Figure 2

Even when the working chamber is completely filled, there is a difference between the drive and fan speed (slip). The resulting heat is dissipated to the ambient air via the cooling fins. The electronically controlled Visco® clutch is controlled directly via sensors. A controller processes the values, and a pulsed control current transmits them to the integrated electromagnet. The defined guided magnetic field controls the valve for controlling the internal oil flow via an armature. An additional sensor for the fan speed closes the control loop.

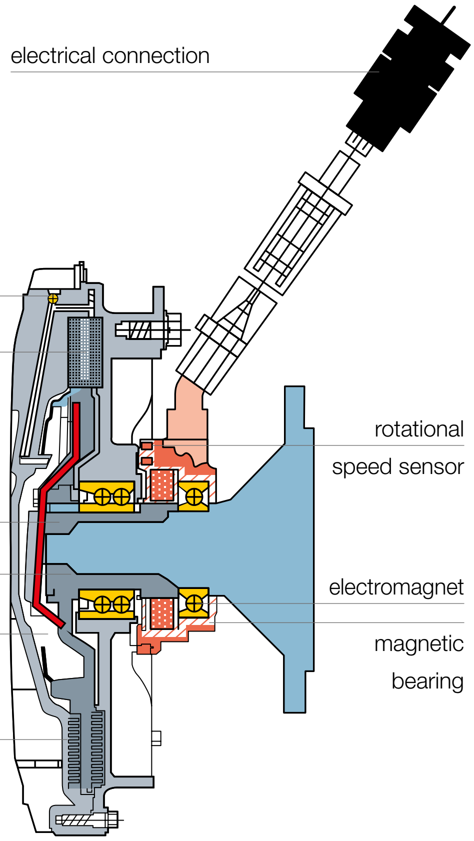
Impact in the event of failure

The following symptoms may indicate a defective Visco® clutch:

- Increased engine or coolant temperature
- Loud noise development
- Fan wheel runs at full speed under all operating conditions

Possible causes may include:

- Poor frictional connection due to oil leakage
- Oil loss due to leakages
- Contamination of the cooling surface or bimetal
- Internal damage (e.g., control valve)
- Bearing damage
- Damaged fan wheel
- Permanent full frictional connection due to faulty clutch



Electronically controlled Visco® clutch

Troubleshooting

Test steps to detect the defect:

- Check coolant level and antifreeze content.
- Check Visco® fan for external contamination and damage.
- Check bearings for play and noise.
- Check for oil leakage.
- Check Visco® clutch by turning it by hand with the engine switched off; the fan wheel should turn easily when the engine is cold and with difficulty when the engine is warm.
- If possible, check the slip of the clutch by comparing the speeds of the fan and drive shaft. With a full frictional connection, the difference (for directly driven fans) must not exceed 5%; an optical revolution counter with reflective strips is suitable for this.
- Check electrical connection (electronically controlled Visco® clutch).
- Check air scoop/air guide plates.
- Ensure sufficient airflow through the cooler.

Optical revolution counter

Oil cooler

General

The cooling of highly thermally stressed oils (engine, transmission, power steering) through oil coolers and the maintenance of an almost constant temperature provides significant advantages. Oil change intervals are extended and the service life of various components is increased. Depending on the requirements, oil coolers are located in/on the engine radiator or directly on the engine block. There are two basic types of oil coolers: air-cooled and coolant-cooled.

Oil cooler for power steering

Design/function

Today, conventional cooling is no longer sufficient for highly loaded vehicle units. For example, the cooling of the engine oil is very uneven, as it depends on the outside temperature and the airstream. Air-cooled oil coolers, located in the airflow at the front of the vehicle, help to cool the oil temperature sufficiently. Liquid-cooled oil coolers are connected to the coolant circuit of the engine and offer optimal temperature regulation. Coolant flows through the oil cooler. When the engine is warm, the coolant extracts heat from the oil and cools it down. When the engine is cold, the coolant heats up faster than the oil and thus supplies heat to the oil. This allows the oil to reach its operating temperature faster. It is especially important for automatic transmissions and power steering that the operating temperature is reached quickly or a constant operating temperature is maintained. Otherwise, there is a risk that the steering will become too heavy or too light, for example. Today, tubular coolers are increasingly being replaced by compact all-aluminum stacked-plate coolers. These offer greater surface cooling with less installation space and can be installed at various locations in the engine compartment.

Oil cooler for retarder

Engine oil cooler

Impact in the event of failure

The following symptoms may indicate a defective oil/air cooler:

- Poor cooling performance
- Oil loss
- Increased oil temperature
- Contaminated coolant

Possible causes may include:

- Poor heat exchange due to external or internal contamination (insects, dirt, oil sludge, corrosion)
- Oil loss due to damage (accident)
- Ingress of oil into the cooling system (internal leakage)
- Oil loss due to leaky connections

Troubleshooting

Test steps to detect the defect:

- Check oil and coolant level.
- Check oil cooler for external contamination or damage (hairline cracks).
- Check coolant for contamination/ discoloration and antifreeze content.
- Check for external leaks (connections).
- Check flow volume (clogging with foreign materials, corrosion, oil sludge, etc.)

Oil cooler for hydrodynamic retarders

General

Hydrodynamic (fluid-operated) retarders are used in commercial vehicles to support the actual braking system as an almost wear-free hydrodynamic brake. The kinetic energy converted into heat, which is generated by decreasing the flow velocity of the oil must be transferred back to the cooling system through a heat exchanger. The use of the retarder is either activated by the driver or initiated automatically. The brake power is several hundred kW.

Design/function

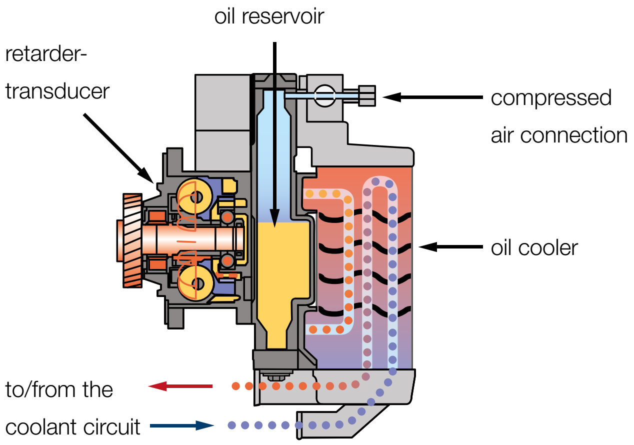
In addition to the service brake of a commercial vehicle, which is usually a wearing friction brake, vehicle manufacturers are increasingly using additional, wear-free deceleration devices. One type of construction is the hydrodynamic retarder, which can be attached or installed in various ways. A distinction is made between external and internal retarders. External retarders can be freely positioned in the powertrain area, while internal retarders are partially or fully integrated into the transmission. Retarders are available in the "inline" (integrated in the powertrain) and "offline" (flanged to the side of the transmission) variants.

All variants have several common goals:

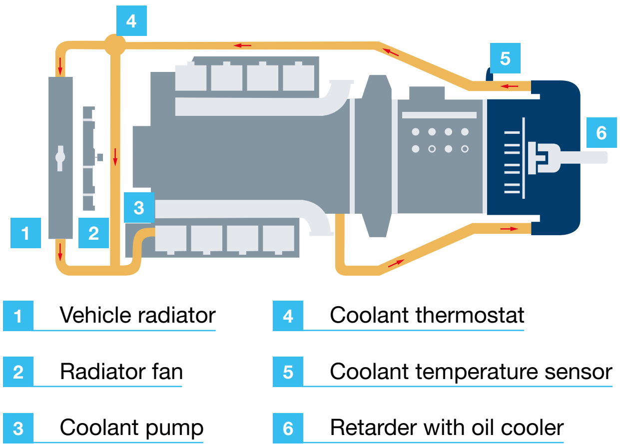
- Reducing vehicle speed
- Keeping speed constant on gradients
- Minimizing wear on the service brake
- Protecting the service brake from overload

Hydrodynamic retarders (see Figure 2 on the following page) usually work with oil (sometimes also with water) and have an internal or external oil reservoir, which feeds into a converter housing during the braking process with the help of compressed air. The housing consists of two blade wheels facing each other, a rotor connected to the vehicle's powertrain, and a fixed stator. The rotor accelerates the supplied oil. Because of the shape of the rotor blades and the centrifugal force, the oil is guided into the stator, which in turn decelerates the rotor and therefore the powertrain shaft. The thermal energy generated in the retarder heats the oil, which is cooled down again by an oil cooler (see Figure 4 on the following page).

The oil cooler, made of solid aluminum or steel, is flanged to the retarder and transfers the absorbed heat to the vehicle coolant circuit. To prevent the specified limit temperature from being exceeded, a temperature sensor for monitoring the coolant temperature is installed near the oil cooler. The sensor ensures that the retarder is adjusted downward or switched off if the limit temperature is exceeded.



Retarder with attached oil cooler



Cooling circuit with retarder

Impact in the event of failure

The following symptoms may indicate a retarder failure/defect:

- Coolant loss
- Oil loss
- Mixing of oil and water
- Total failure of the braking function

The following possibilities should be considered:

- Overheating of the cooling system due to lack of coolant, incorrect coolant, or incorrect coolant blend
- Overheating of the coolant due to incorrect handling (full vehicle braking at low engine speed, incorrect gear selection) and resulting cavitation (bubbling of the coolant due to high thermal loads); see Figure 3
- Damage to seals/hose connections
- Cross-sectional constrictions due to contamination within the heat exchanger or cooling system
- High or sudden thermal loads (temperature/pressure)
- Internal leaks in the heat exchanger
- Failure of the temperature sensor (Figure 1)

Troubleshooting

The following steps should be used for troubleshooting:

- Check the coolant for compliance with the vehicle manufacturer's specifications (coolant type, mixing proportion).
- Check the coolant level.
- Check the cooling system for leaks and contamination (oil, lime, rust, sealant).
- Check the coolant inlet/outlet for cross-sectional constrictions.
- Check that the heat exchanger is properly secured and has no cracks.
- Check electrical components (sensor).
- Check the function of other components in the cooling system (fan, thermostat, water pump, filler cap).

When replacing the oil cooler, the cooling system should be flushed and the retarder oil and coolant replaced. The cleaning agent used for the cooling system, for example, is suitable for flushing. Separate instructions specific to the vehicle manufacturer must always be observed.

Figure 1

Figure 2

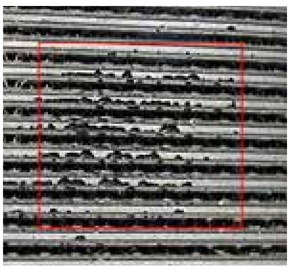


Figure 3

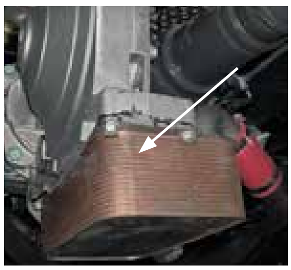


Figure 4

Charge air cooler

General

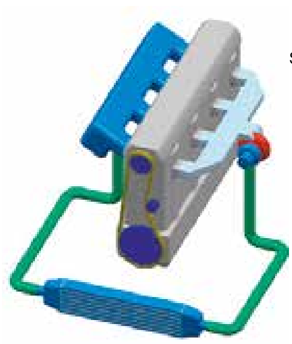
Performance increase over the entire speed range, low fuel consumption, improved engine efficiency, reduced emissions values, reduced thermal load on the engine—there are many reasons to cool the combustion air of turbocharged engines with charge air coolers. There are essentially two types of cooling: direct charge air cooling, where the charge air cooler is installed in the vehicle's front end area and is cooled by the ambient air (airstream), and indirect charge air cooling, where coolant flows through the charge air cooler and dissipates the heat.

Charge air cooler

Design/function

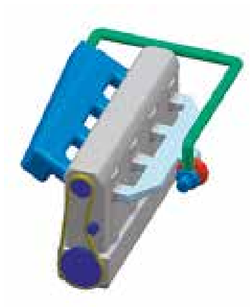
In terms of design, the charge air cooler is equivalent to the radiator. In the charge air cooler (CAC), the medium to be cooled is not coolant, but compressed hot air (up to 150°C) from the turbocharger. In principle, heat can be extracted from the charge air by the outside air or the engine coolant. The charge air enters the CAC and, in the case of the direct charge air cooler, the ambient air flows through it, cooling it before it reaches the engine's intake section. In the case of coolant-cooled CACs, the CAC can be installed in almost any position, with the smaller overall installed size also being an advantage. With indirect charge air cooling, for example, the coolant-cooled CAC and the intake section can form a single unit. Without an additional cooling circuit, however, the charge air can only be lowered to a level close to the coolant temperature. With the aid of a separate CAC coolant circuit independent of the engine coolant circuit, the efficiency of the engine can be further improved by increasing the air density.

A low-temperature radiator and a charge air cooler/radiator are incorporated in this circuit. The charge air's waste heat is initially transferred to the coolant and then dissipated to the ambient air in the low-temperature radiator. The low-temperature radiator is housed in the vehicle's front end. Since the low-temperature radiator needs significantly less space than a conventional air-cooled CAC, space is freed up in the front end. Additionally, the bulky charge air lines are no longer needed.



schematic diagram

Direct charge air cooling



Indirect charge air cooling/intake manifold with integrated CAC

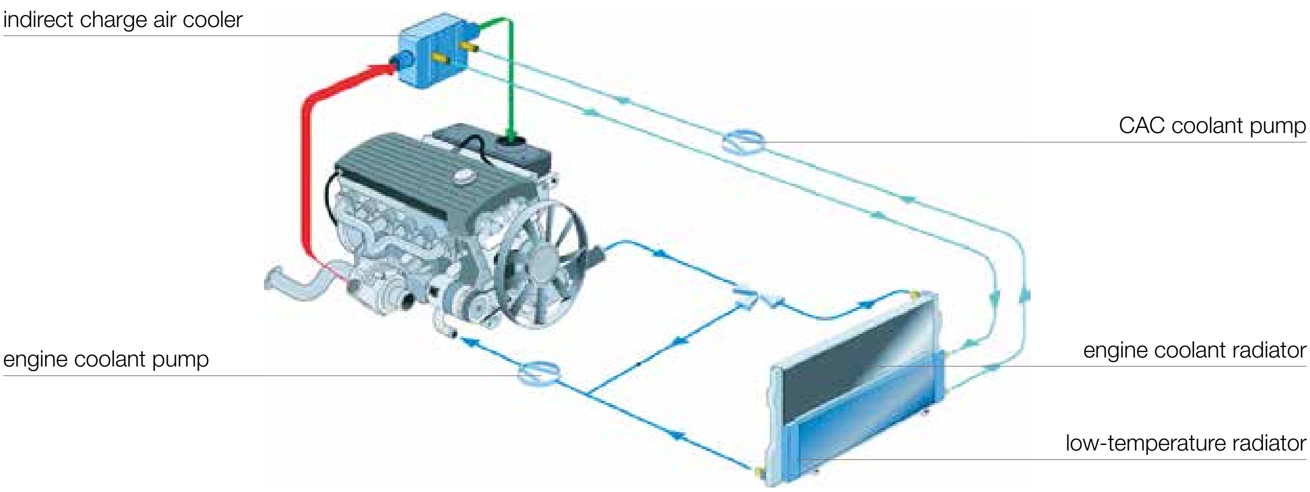
Impact in the event of failure

The following symptoms may indicate a defective charge air cooler:

- Inadequate engine output
- Coolant loss (with a coolant-cooled CAC)
- Increased emissions
- Increased fuel consumption

Possible causes may include:

- Damaged or blocked hose/coolant connections
- Coolant loss or air infiltration due to leakage
- External damage (stone chips, accident)
- Reduced airflow rate (dirt)
- Poor heat exchange due to internal contamination (corrosion, sealant, limescale deposits)
- Coolant pump failure (with a low-temperature radiator)



Troubleshooting

Test steps to detect the defect:

- Check the coolant level.
- Check coolant for contamination/ discoloration and antifreeze content.
- Check for external damage and contamination.
- Check system components and connecting elements (hose connections) for leaks.
- Check coolant pump.
- Check fans and auxiliary fans.
- Check flow volume (clogging with foreign materials or corrosion).

Coolers for exhaust gas recirculation (EGR)

General

One way of meeting the stringent Euro 6 limits for nitrogen oxide emissions (NO_x) is cooled exhaust gas recirculation (EGR). Some of the primary exhaust gas flow between the exhaust manifold and the turbocharger is extracted, cooled in a special heat exchanger (EGR cooler), and fed back into the intake air. This decreases the combustion temperature in the engine, reducing the formation of nitrogen oxides.

Removed EGR cooler

Design/function

The EGR cooler, installed close to the engine, is made of stainless steel or aluminum. It is equipped with several connections via which hot exhaust gases and coolants can flow into the cooler. After the exhaust gases have been cooled down in the cooler, they leave the cooler and are fed in metered doses to the intake system and thus to the combustion chamber. This leads to a reduction in nitrogen oxide emissions even before reaching the catalytic converter. Pneumatic and/or electric actuators are installed on the EGR cooler to control the exhaust gas recirculation rate.

Causes of failure and impact

Although the EGR cooler is not a classic wear part, defects due to extreme temperature fluctuations or missing or aggressive coolant additives, for example, can lead to internal or external leaks. Moreover, it is possible that the actuators will fail. One sign of a leaky EGR cooler may be a gradual loss of coolant, frequently coupled with an increased engine temperature.

The loss goes unnoticed at first, as the exhaust back pressure is higher than the coolant pressure when the engine is running. When the engine is switched off, the pressure decreases and coolant escapes in the intake or exhaust gas tract of the engine. If the radiator is higher than the inlet and exhaust valves, this can lead to an accumulation of coolant in the combustion chamber. When restarting the engine, “water hammer” can cause mechanical damage to the engine components.

With a cracked EGR cooler, the exhaust gas pressure can escape uncontrollably and will no longer be sufficiently available to the turbocharger. This results in a lack of boost pressure or inadequate engine performance. The actuators installed on the EGR cooler can fail—e.g., due to leaks, torn diaphragm (pneumatic), electrical faults (actuation, contact), or mechanical faults (drive/actuation sluggish or broken).

Another possible cause of failure is internal carbon buildup in the EGR cooler. Many of the above errors are detected by the control unit and cause the engine control lamp to light up.

Troubleshooting

The location where the EGR cooler is installed can often make troubleshooting difficult. However, there are various ways to test components and determine the cause of the defect:

1. Read out fault memory

- Reading out the fault memory provides information about the area in which the defect is located.

2. Monitor measured value blocks

- By comparing setpoint and actual values, conclusions can be drawn about the function and position of components.

3. Visual and acoustic testing

- With the help of a visual and acoustic test, leaks (coolant, exhaust gas, pressure/vacuum) and contamination can be detected.

4. Mechanical testing

- Mechanical drives (servomotor) should be checked for function and ease of movement.

5. Pressure/vacuum testing

- A pressure/vacuum pump can be used to test pneumatic components (vacuum actuator/valves/pressure converters) and hose lines.

6. Using the multimeter

- The power supply to electrical components can be tested with the multimeter.

7. Testing with the oscilloscope

- Use of the oscilloscope is particularly recommended when testing component control (PWM signal).

Before starting the diagnostics process, an overview of the system and the installed components should be obtained from vehicle-specific documents (wiring diagram, test values). This will facilitate structured troubleshooting.

EGR cooler: mechanical actuation

EGR cooler with servomotor and vacuum actuator

PTC auxiliary heater

General

Because of the high efficiency of modern direct-injection engines (e.g., TDI), the waste heat is no longer sufficient to heat up the vehicle cabin quickly on cold days. PTC auxiliary heaters, which are installed in front of the heat exchanger in the direction of travel, cause the cabin to heat up more quickly. These heaters consist of several temperature-dependent, electrically controlled resistors. Energy is taken immediately from the electrical system and directly transferred to the vehicle cabin as heat via the blower airflow.

PTC auxiliary heaters

Design/function

PTC elements are nonlinear ceramic resistors. PTC stands for positive temperature coefficient, which means that the electrical resistance increases with the temperature of the element. However, this is not exactly true, because at first it drops as the temperature rises. The resistance characteristic curve has a negative temperature characteristic in this range. Once the minimum resistance is reached, the negative temperature characteristic changes to a positive one—i.e., as the temperature continues to rise, the resistance first drops slowly, then increases sharply above approx. 80°C until the PTC heating elements absorb practically no additional current. At this point, when no air is flowing through the PTC heater, the surface temperature is about 150°C and that of the metal frame approximately 110°C. The PTC heater consists of several heating elements, a mounting frame, an insulating frame, and the relays or power electronics.

The heating elements are composed of PTC ceramic bricks, contact sheets, terminals, and aluminum corrugated fins. The corrugated fins increase the heat-emitting surface of the contact sheets. To increase the air-side heat transfer, the fins have slits known as “gills.” Thanks to the improved heat transfer, the excessive increase in cut-in current can be significantly reduced compared with auxiliary heaters without gill fins. This has the advantage that individual PTC strands can be switched on more frequently—i.e., the heater can be operated with a higher overall output. The production know-how for these “gills” comes from radiator production. The auxiliary heater is located in the heating/air conditioning unit in the airflow directly behind the conventional heat exchanger, which keeps the package requirements to a minimum. When outside temperatures are low and the engine is cold, only cold air, or air slightly heated by the heat exchanger, flows through the PTC heater initially. The temperature and resistance of the heating elements are low, but the heating performance is high. When the conventional heater responds, the air temperature and resistance increase and the heating performance decreases accordingly. At the surface temperature of a PTC heater, with warm 25°C air flowing through it, a volume flow of approx. 480 kg of air per hour is achieved. The heating network reaches a mean temperature of 50°C at this air temperature. A different nominal resistance can be selected for the PTC elements, which will alter the current consumption and performance accordingly. A low nominal resistance allows a high heating performance during operation. The output of PTC heaters is between 1 and 2 kW. At 2 kW, the power limit of the 12 V network (150 A at 13 V) is reached. Higher outputs would be possible with a 42 V electrical system. Because of its low mass and the fact that the electrically generated heat is transferred directly to the airflow without any detours, the PTC heater responds almost immediately. This high spontaneity is the characteristic feature of the PTC auxiliary heater. As the engine reaches operating temperature more quickly as a result of the additional load on the generator, the conventional heater also responds more quickly. This additional heating capacity is around two-thirds of the capacity of the PTC heater. In practice, this heating capacity can be assigned to the PTC heater. The characteristic resistance curve of the PTC elements prevents the PTC heater from overheating. The temperature on the surface of the metal frame is always below 110°C. In addition, the output of the PTC heater is reduced at the higher discharge temperatures reached by the heat exchanger. Power electronics allow the PTC heater to be controlled in several stages or in a continuously variable manner, so that it can be adapted to the required heating performance or the available electrical output. The PTC heater is controlled either externally with relays or by means of an integrated control system with power electronics. With relay control, the vehicle manufacturer determines which and how many stages are switched on.

The control system integrated in the auxiliary heater distinguishes between minimum and high functionality. At minimum functionality, the stages are switched on individually.

The power electronics protect the auxiliary heater from overvoltage, short circuit, and reverse polarity. No diagnostics functionality is provided with this control system. Up to eight stages are possible with stepped control. The control is dependent on the power balance and auxiliary heating requirements—i.e., the desired thermal comfort. In the case of high-functionality control, the power electronics are controlled steplessly, for example, via the vehicle's LIN or CAN bus. This means that the electricity provided by the electrical system in every situation can always be optimally utilized for auxiliary heating. In addition to protection against overvoltage, short circuit, and reverse polarity, the power electronics with high functionality include overload protection for each stage, protection of the printed circuit board against overheating, and voltage monitoring. Diagnostics can be run on the high-functionality control system.

Impact in the event of failure

The following symptoms may indicate a defective PTC auxiliary heater:

- Reduced heater performance when the engine is cold
- Error code stored in the fault memory

Possible causes may include:

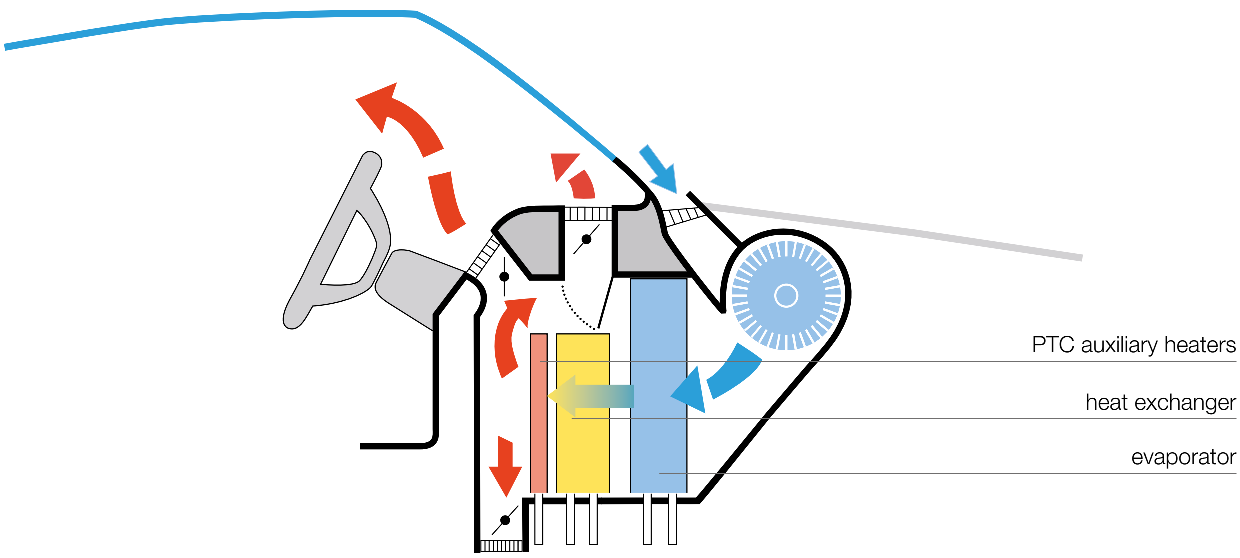
- Faulty electric actuation or electrical connections of the PTC auxiliary heater
- PTC auxiliary heater defective (power electronics, resistors)

Troubleshooting

Test steps to detect the defect:

- Check fuse.
- Read out fault memory.
- Read out measured value blocks.
- Check electric actuation (relays).
- Check electrical connections.

In many vehicles, the control unit of the electrical system uses “load management” to regulate the PTC auxiliary heater and switches it off if the electrical system is overloaded. The load management status can often be viewed via the measured value blocks. If there are any issues with heating performance, the fault memory and the measured value blocks can be read out to determine whether an overload of the electrical system has caused the auxiliary heater to be switched off. A defective auxiliary heater can also be the cause of an overload.



Arrangement of heat exchanger/auxiliary heater in the vehicle cabin

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