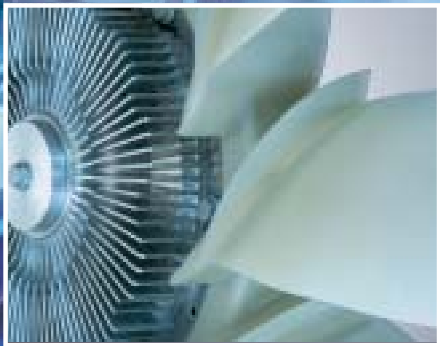
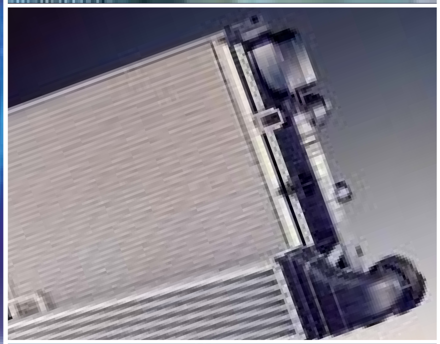
Engine Cooling – comprehensive knowledge for garages!





BEHR HELLA
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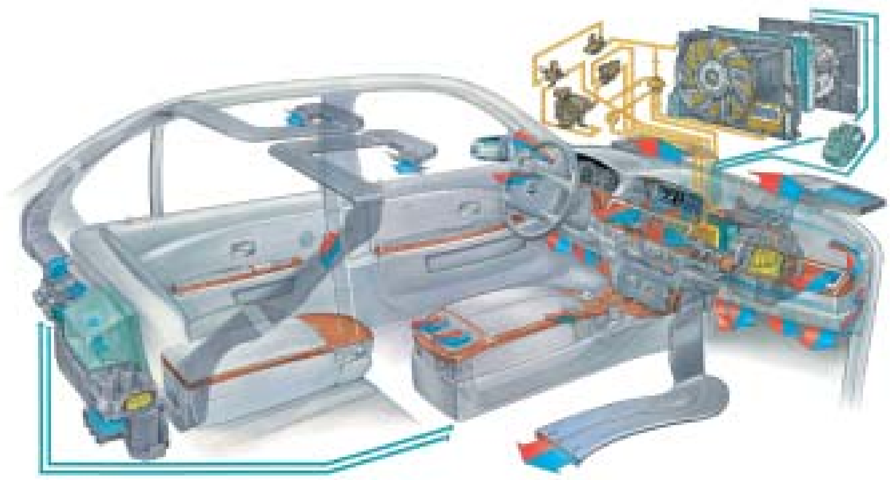
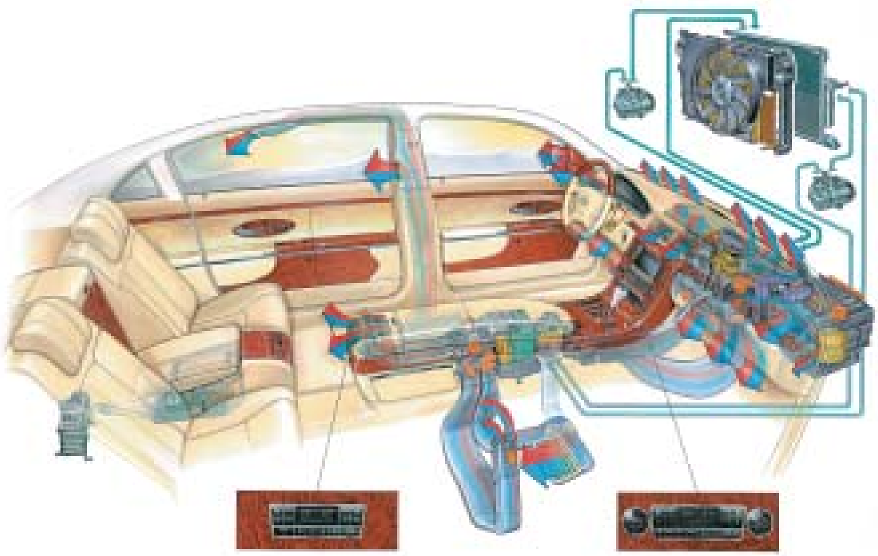
What is thermal management?

Thermal management refers to optimum engine temperature in all operating states, as well the heating and cooling of the vehicle interior. Consequently, a modern thermal management system consists of engine-cooling and air-conditioning components. Components of these two assemblies often form units that influence each other. In this booklet, we describe modern cooling systems and their technical background. In the relation to this, we explain the function, causes of failure, features and diagnostic possibilities.

1.1 Integrated System – Passenger Cars

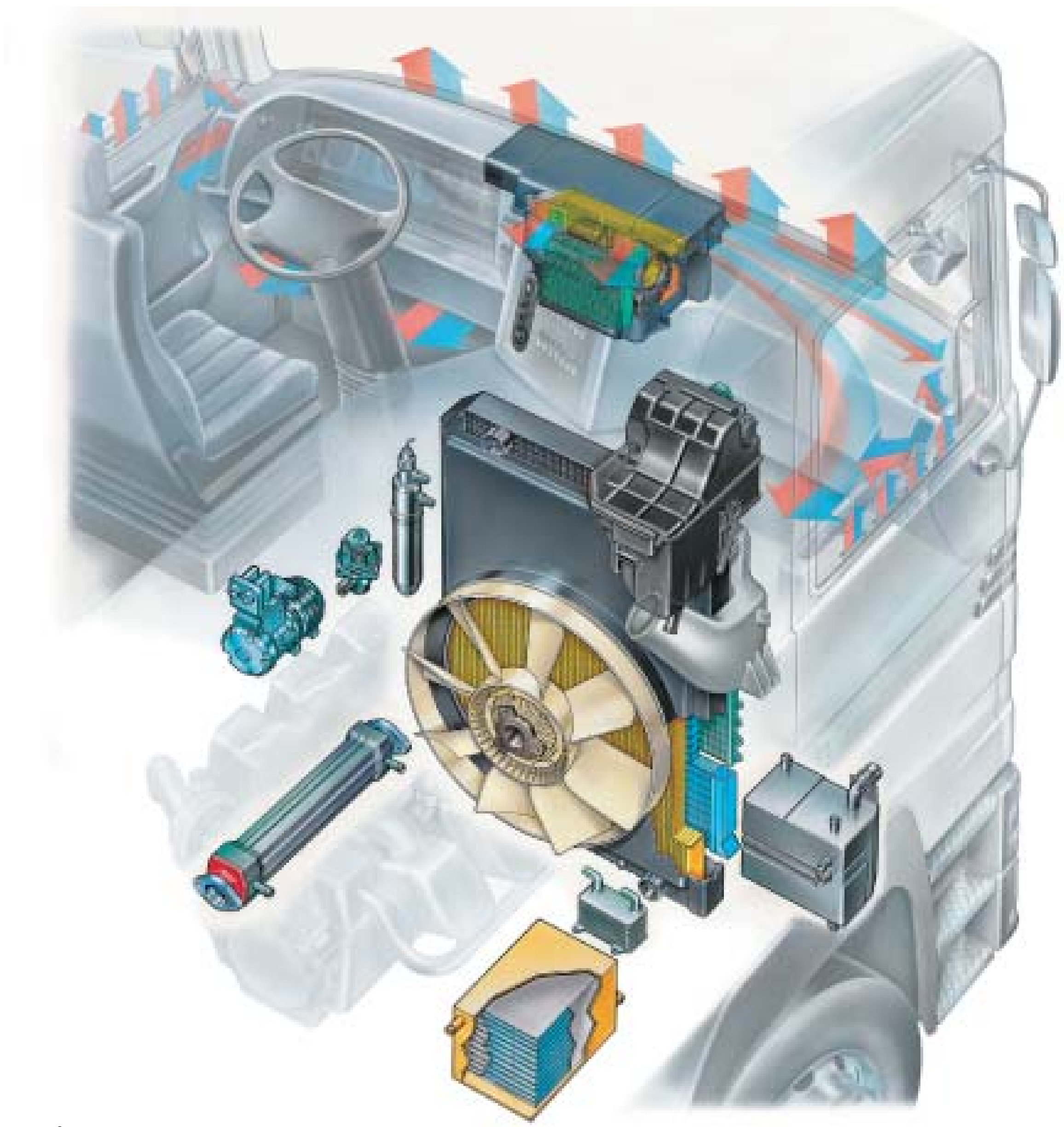
A typical example of a modern Thermal Management system in passenger cars. Thermal Management is an important subject for the manufacturers. All heat generated in the engine and its independent systems must be dissipated. Thermal Management is needed today to control operation and ambient temperature (engine and passenger compartment), because the operating temperature of an engine must remain within narrow borders. An increased operating temperature may worsen the exhaust gas values which may lead to incorrect engine control. Additionally, a cooling system must warm the passengers in winter and cool them in summer when engine types such as direct injection, diesel and petrol engines produce low quantities of heat. All those factors need to be taken into account when a Thermal Management system is developed. Moreover, there is the requirement of higher performance and improved efficiency in small installation spaces.





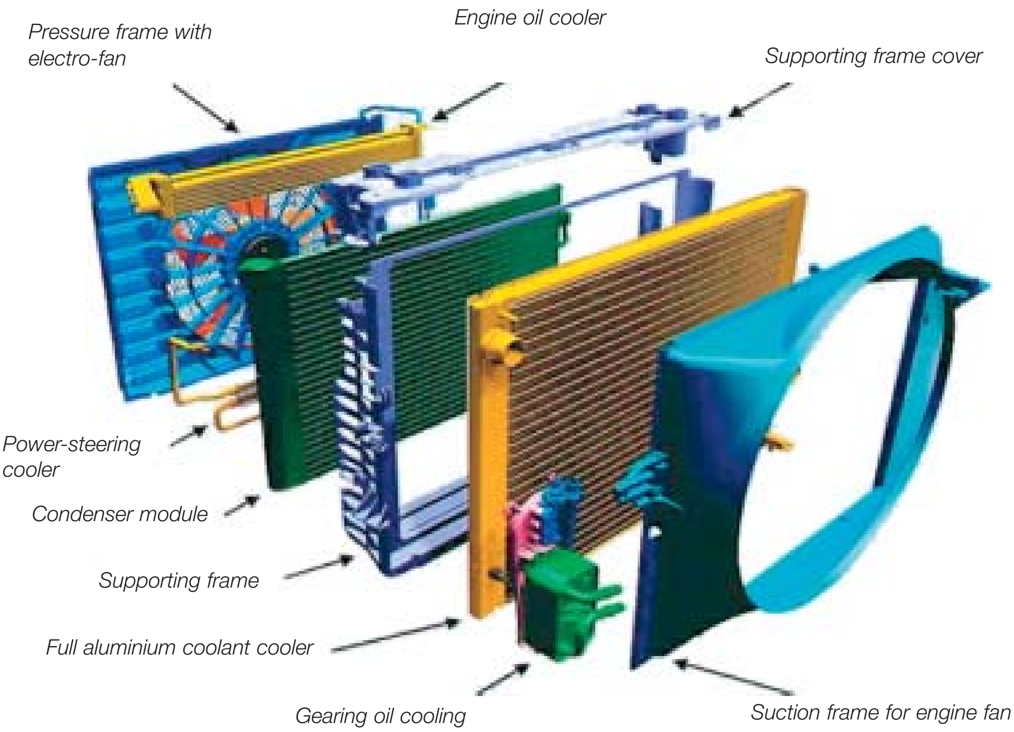
1.2 Integrated System – Commercial Vehicles

A typical example of a modern Thermal Management system in commercial vehicles. In this guide we will be looking at both passenger cars and commercial vehicles.



1.3 Structure of a Modern Cooling Module

A typical example of a modern cooling module. The module consists of coolant cooler, engine oil cooler, condenser, gearing oil cooler, power steering cooler and condenser fan.



2.1 Engine Cooling with Water

The temperatures generated when the fuel is burnt (up to 2,000 °C) are detrimental to engine operation. Therefore, the engine is cooled down to operating temperature. The first kind of cooling with water was thermosiphon cooling. The heated, lighter water rises into the upper part of the radiator through a manifold and is cooled by the air flow around the radiator. It then sinks down and is returned to the engine. The water is circulating while the engine is running. Cooling was supported by the fan, but regulation was not possible. Later, a water pump accelerated the water circulation.

Weak points:

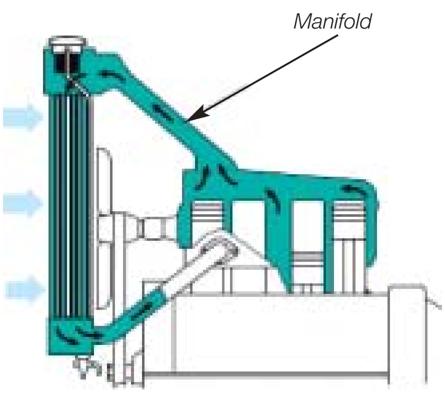
- Long warm-up time
- Low engine temperature during the cold time of the year

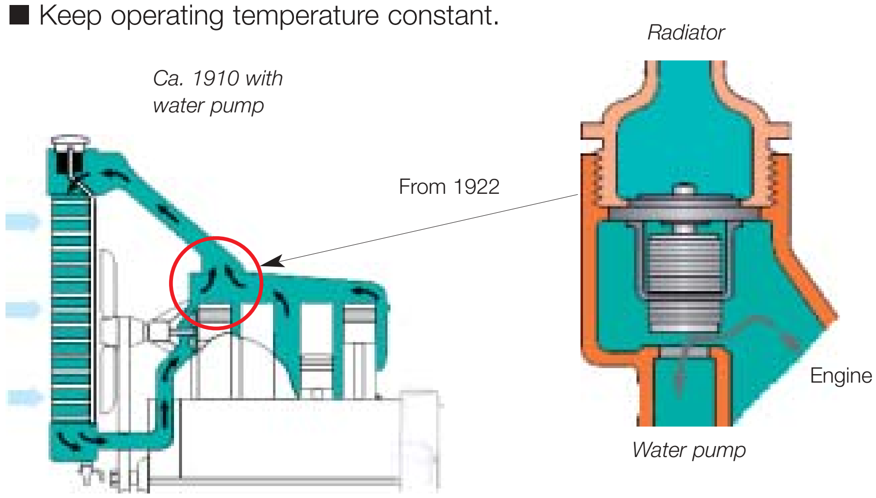
In the further development of engines, cooling water regulators (i.e. thermostats) were used.

The water circulation through the radiator is regulated in dependence on the cooling water temperature. In 1922, it was described as follows: “The purpose of these devices is quick engine heating and prevention of cooling down of the engine.“

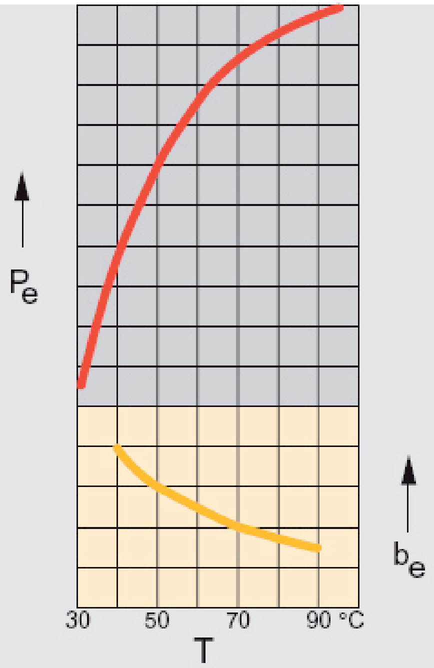
We are referring to a thermostat-controlled cooling system with the following **functions:**

- Short warm-up time
- Keep operating temperature constant.





2.2 Present State



P_e = power
b_e = fuel consumption
T = engine temperature

The thermostat was a decisive improvement and enabled a short-circuit water pipe. While the desired engine operation temperature is not reached, the water does not run through the radiator, but by-passes it and runs into the engine. That control system has remained the basis of all systems, right up to today.

The influence which the engine temperature has on performance and fuel consumption is shown in the diagram below.

However, today the correct operating temperature of the engine is not only important with regard to performance and fuel consumption, but also for low emission of pollutants.

Engine cooling uses the fact that pressurised water does not boil at a temperature of 100 °C, but between 115 °C and 130 °C. The cooling circuit is under a pressure of between 1.0 bar and 1.5 bar. We are referring to a closed cooling system. The system has an expansion tank which is only around half filled. The bellow expansion joint is replaced by an expansion material regulator (wax regulator). The cooling medium is not just water, but a mixture of water and coolant additive - a coolant which provides anti-freeze protection, has an increased boiling point and protects the engine's light metal parts against corrosion.

3.1 The Engine Cooling System

We all know that the engine compartment has become pretty crowded and therefore a considerable amount of heat is produced which needs to be dissipated. The cooling of the engine compartment makes high demands on modern cooling systems and therefore good progress has been made recently in cooling technology.

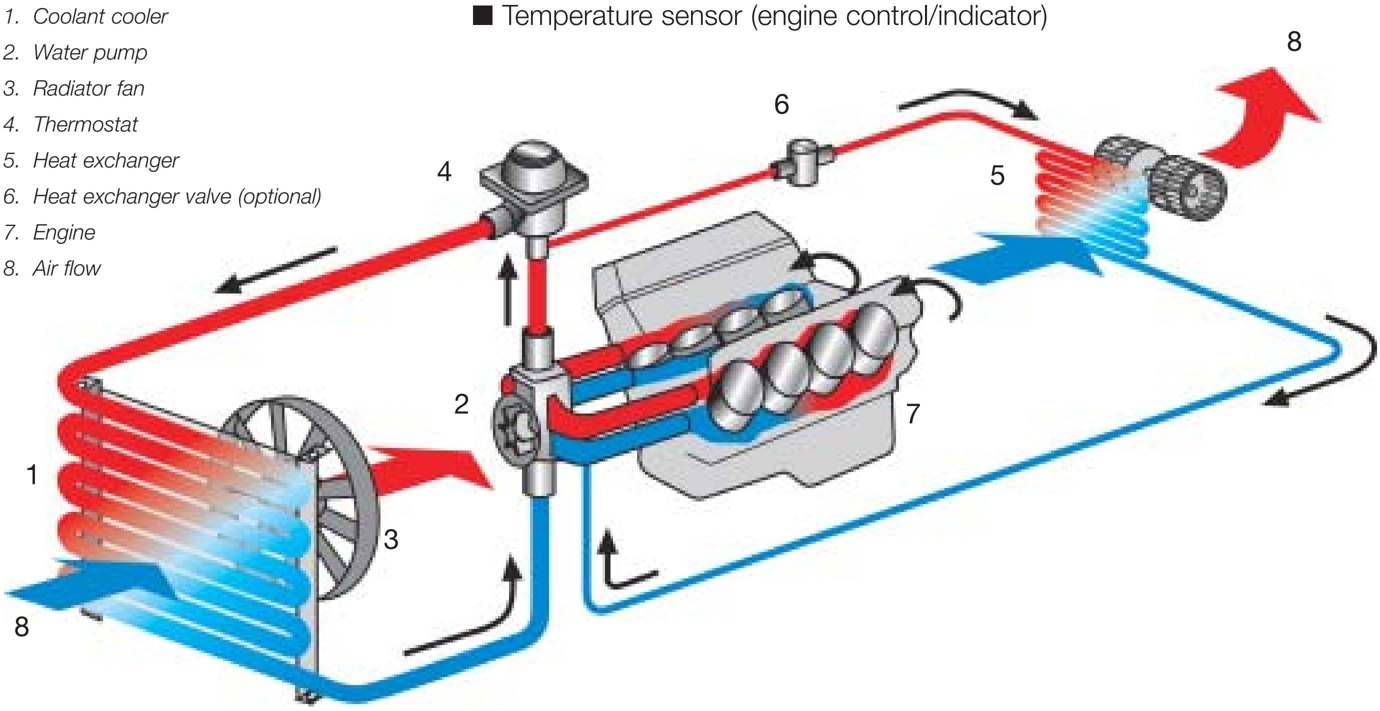
The requirements made on the cooling system are:

- Shorter warm-up phase
- Fast passenger compartment heating
- Low fuel consumption
- Longer service life of the components

All engine cooling systems are based on the following components:

- Coolant cooler
- Thermostat
- Coolant pump (mechanical or electrical)
- Expansion tank
- Pipes
- Engine fan (V-belt driven or Visco®)
- Temperature sensor (engine control/indicator)

1. Coolant cooler
2. Water pump
3. Radiator fan
4. Thermostat
5. Heat exchanger
6. Heat exchanger valve (optional)
7. Engine
8. Air flow



3.2 Coolant Cooler

From 1905 on, engines began to be cooled. The combustion temperature in the engine at the time was around 600 °C – 800 °C. Steel coolers were used from the turn of the century until around 1938, then nonferrous heavy metal radiators (copper/brass) were used. Drawbacks: Heavy, made of a limited resource, high price of copper.

Requirements on the radiator:

- High power density
- Sufficient stability
- Permanent resistance to corrosion
- Low production costs
- Environmentally compatible production

Design
- Water box made of GRP = glass fibre reinforced polymer
- Increasingly made of aluminium

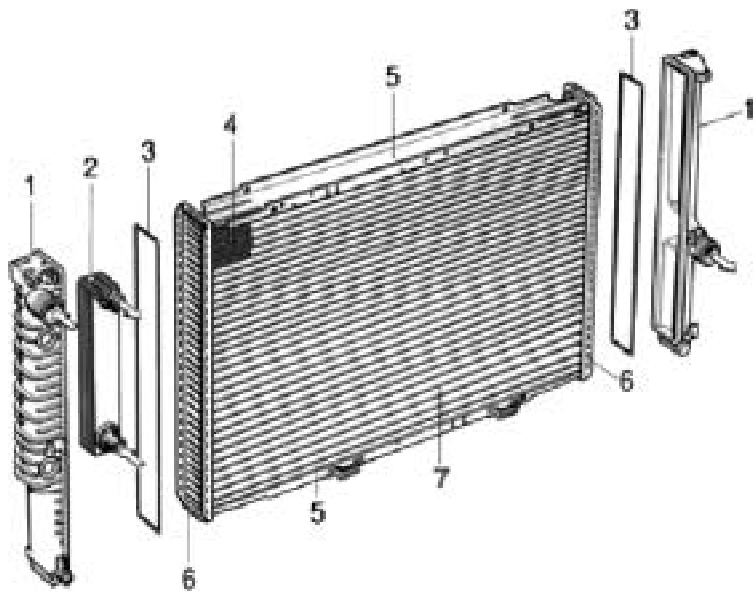
Task
- Cool the coolant in the engine circuit

Advantages
- Accurate-fit installation for easy assembly
- Optimal efficiency
- Tailored to customer specifications (OEM)

3.2.1 Typical Design

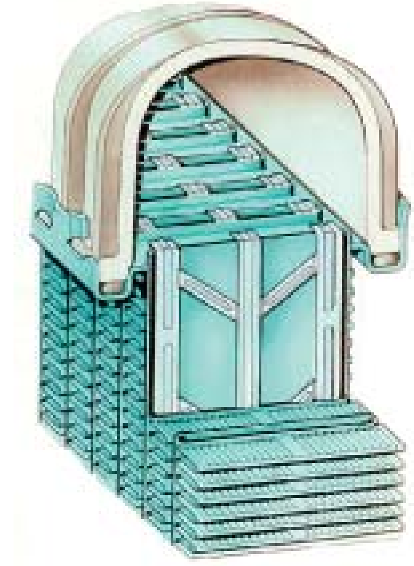
Typical structure of a coolant cooler: The oil cooler may be a separate component. The individual components are assembled to give the coolant cooler its form.
Cooling is effected by means of cooling fins (mesh). The air flowing through takes heat out of the coolant. The coolant flows from top to bottom, which is called downdraft, or with a cross flow (right to left or vice versa). For both variants, sufficient time and a sufficient cross-section are necessary for the air to efficiently cool the coolant.

1. Water box
2. Oil cooler
3. Seals
4. Cooling fin (mesh)
5. Side plates
6. Bottom
7. Radiator tube

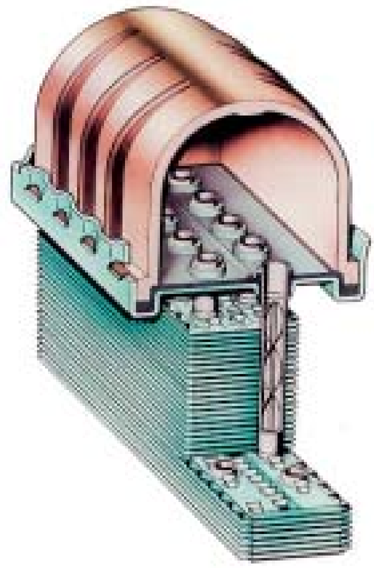


3.2.2 Design Types

Two typical designs: soldered and mechanically fitted. Both are downdraft coolers. At first the radiators were equipped with brass water boxes, later with plastic water boxes. Cross-flow coolers are 40% smaller than downdraft coolers and are used in passenger cars today where a more flat type of construction is required. The water box is fastened and sealed with a wave-slot flanging developed by Behr. Another type of fastening is tab flanging. Downdraft coolers are installed in higher passenger cars (cross-country vehicle etc.) or commercial vehicles.



Soldered



Mechanically fitted

3.2.3 Full Aluminium Radiator

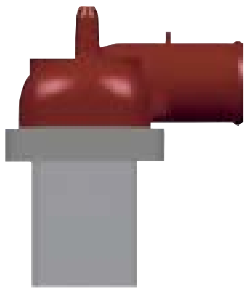
As you can see, the full aluminium radiator has a considerably reduced mesh depth. This type of construction helps reduce the overall depth of the radiator module. For example, the entire full aluminium radiator of the Audi A8 is 11% lighter and has a 20 mm smaller depth.

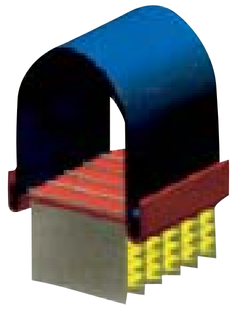
This type of construction has the following characteristics:

- Top and bottom not needed
- No tools needed for production, seal and water box
- Mesh depth equals radiator depth
- 5% – 10% less weight
- Higher operational stability
- Bursting pressure 5 bar
- Can be recycled as a whole
- Transportation damage is reduced (overflow sockets)
- Various pipe types can be used
- Circular tube with turbulence insert in the case of higher capacity
- Oval tube (means more surface for cooling)
- Flat tube mechanical production (more surface area yet only one row necessary)
- Flat tube soldered without fluxing agent (best cooling, lamellae fit tight 100%), but expensive
- Special aluminium alloy is used (mesh)
- Temperature 600 °C – 650 °C, then cooling down to around 130 °C (tension is equalised)

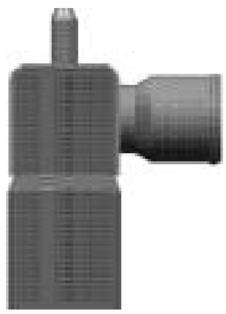
This comparison shows the difference between a radiator with GRP bottom and a full aluminium coolant cooler. It is clearly visible that the overall depth is considerably reduced which allows space-saving installation within a modern cooling module.

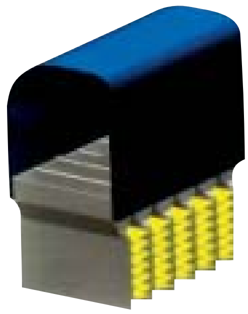
Mesh depth *40mm*
Overall depth *63,4mm*





Mesh depth *40mm*
Overall depth *40mm*





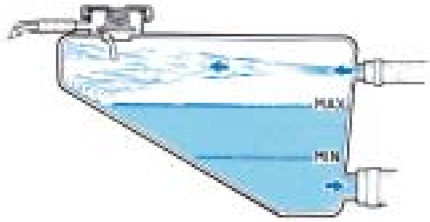
3.3 Expansion Tank

To prevent local overheating of the components, the coolant circuit must not contain bubbles.
The coolant exits into the tank at great speed, due to different diameters of the openings.

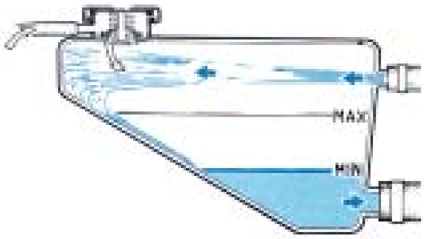
- *System pressure 1.7 bar*
- *Bursting pressure 10 bar*

For comparison, commercial vehicles have three chambers and a large quantity of water, e.g. 8 litres coolant. The expansion tank holds expanded coolant from the coolant circuit. The pressure is relieved by a valve and thus the system pressure is kept at a set value.

3.3.1 Function



High coolant temperature results in the pressure in the cooling system rising, because the coolant expands. Coolant is pressed into the tank. The pressure in the tank rises. The pressure relief valve in the valve cap opens and lets air escape.



When the coolant temperature normalises, a vacuum is generated in the cooling system. Coolant is sucked out of the tank and a vacuum is also generated in the tank. The pressure relief valve in the valve cap opens and air flows into the tank until the pressure is equalised.

3.4 Thermostat

Thermostats control the temperature of the coolant and thus the engine temperature. Mechanical thermostats have not changed much through the years and are still installed. The function is provided by an expanding wax element which opens a valve and returns coolant to the coolant cooler to be cooled. The thermostat opens at a certain temperature which is set for the system and cannot be changed. Electronically controlled thermostats are controlled by the engine management and open depending on the engine's operating conditions. Electronically controlled temperature regulators contribute to reducing fuel consumption and pollutant emissions by improving the engine's mechanical efficiency.

Wax element

Electronically controlled

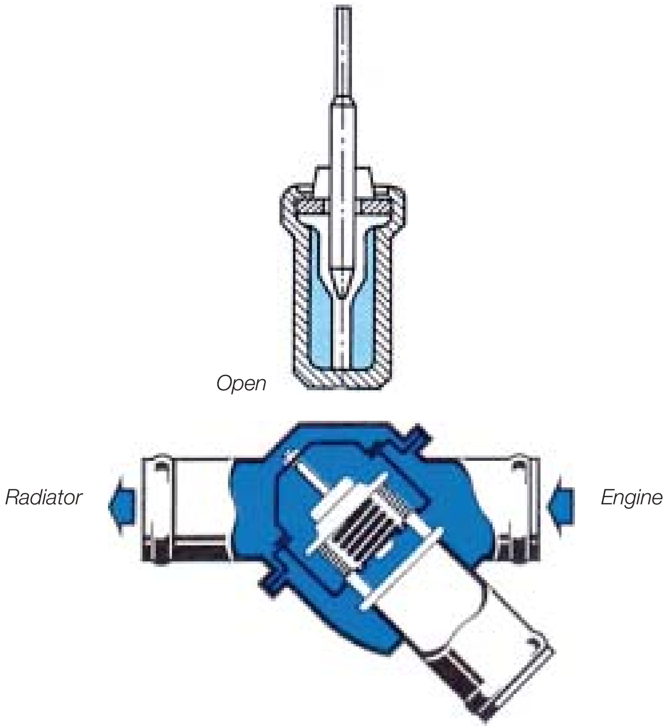
Advantages:

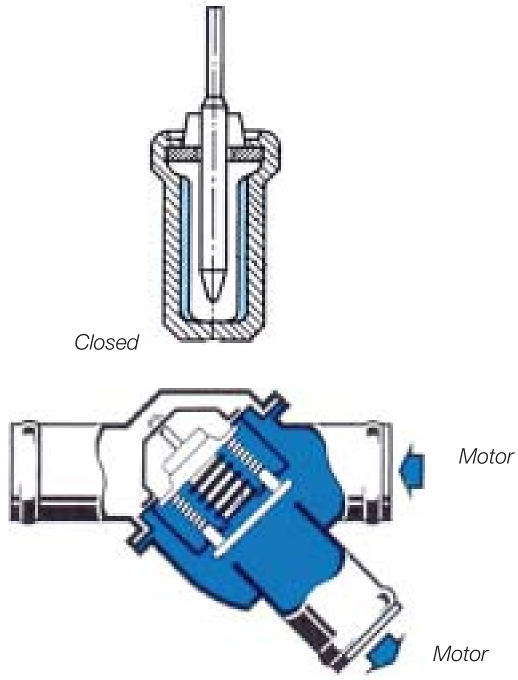
- Reduction of fuel consumption by around 4%
- Reduction of pollutant emissions
- Enhanced comfort (by improved heating power)
- Longer engine life
- Preservation of the flow conditions and the thermodynamic conditions
- Demand-oriented temperature regulation
- Highest temperature change rate
- Lowest increase in construction volume (< 3%)

3.4.1 Function

The wax filling melts when heated to more than 80 °C. The volume increase of the wax moves the metal box along the working piston. The thermostat opens the cooling circuit and at the same time closes the short-circuit loop.

When the temperature sinks below 80 °C, the wax filling solidifies. A restoring spring presses the metal box back into normal position. The thermostat shuts off the flow to the radiator. The coolant flows directly back to the engine via the short-circuit loop.





3.5 Water Pumps

Water pumps transport the coolant through the circuit and build up the pressure. The water pumps are also affected by technical advance, but many passenger cars and trucks with belt-driven water pumps are still available. However, the next generation will be electronically controlled water pumps. Those water pumps are operated as required, similar to the compressor in the air-conditioning circuit which we all know. This optimises the operating temperature.

3.6 Heat Exchanger (Heating Radiator)

The heat exchanger or heater radiator supplies heat which is transported into the passenger compartment with the air flow of the blower. If an air-conditioning system is installed, which is mostly the case today, a mixture of cold and warm air is generated by the climate control. Here, all three systems get together: heat, cold and appropriate control = air-conditioning of the passenger compartment.

Characteristics:

- Fully recyclable
- Guarantees desired passenger compartment temperature
- Soldered full aluminium heater radiators
- Low space consumption in the passenger compartment
- High heating power
- End bottoms soldered and not clamped
- Installed in the heating box
- Design - mechanically fitted
- Pipe fin system
- With turbulence inserts to improve heat transmission
- Gill fields in the fins enhance efficiency
- State of the art: made of aluminium like the coolant cooler

The engine fan transports the ambient air through the coolant cooler and over the engine. It is driven by V-belts or in the case of the an electrical fan by an electric motor controlled by a control unit.
The Visco® fan is mostly used in the commercial vehicle area, but also in passenger cars.
The engine fan guarantees the flowing through of a sufficient quantity of air to cool the coolant. In the case of V-belt driven fans, the quantity of air depends on the engine speed. The difference to the condenser fan is that it is permanently driven.
The Visco® fan control is dependent on the operating temperature.

Fig. 1

Fig. 2

4.1 Visco® Fan

Visco® Fan

Visco® is a Behr product and a registered product name. Visco® clutches are used in passenger cars and Visco® fans in commercial vehicles.

Function:
Switch-on point full at approx. 80 °C. Filled with silicone oil as motive agent (30 ml to 50 ml), switched on by bimetal and actuated via the pressure pin.

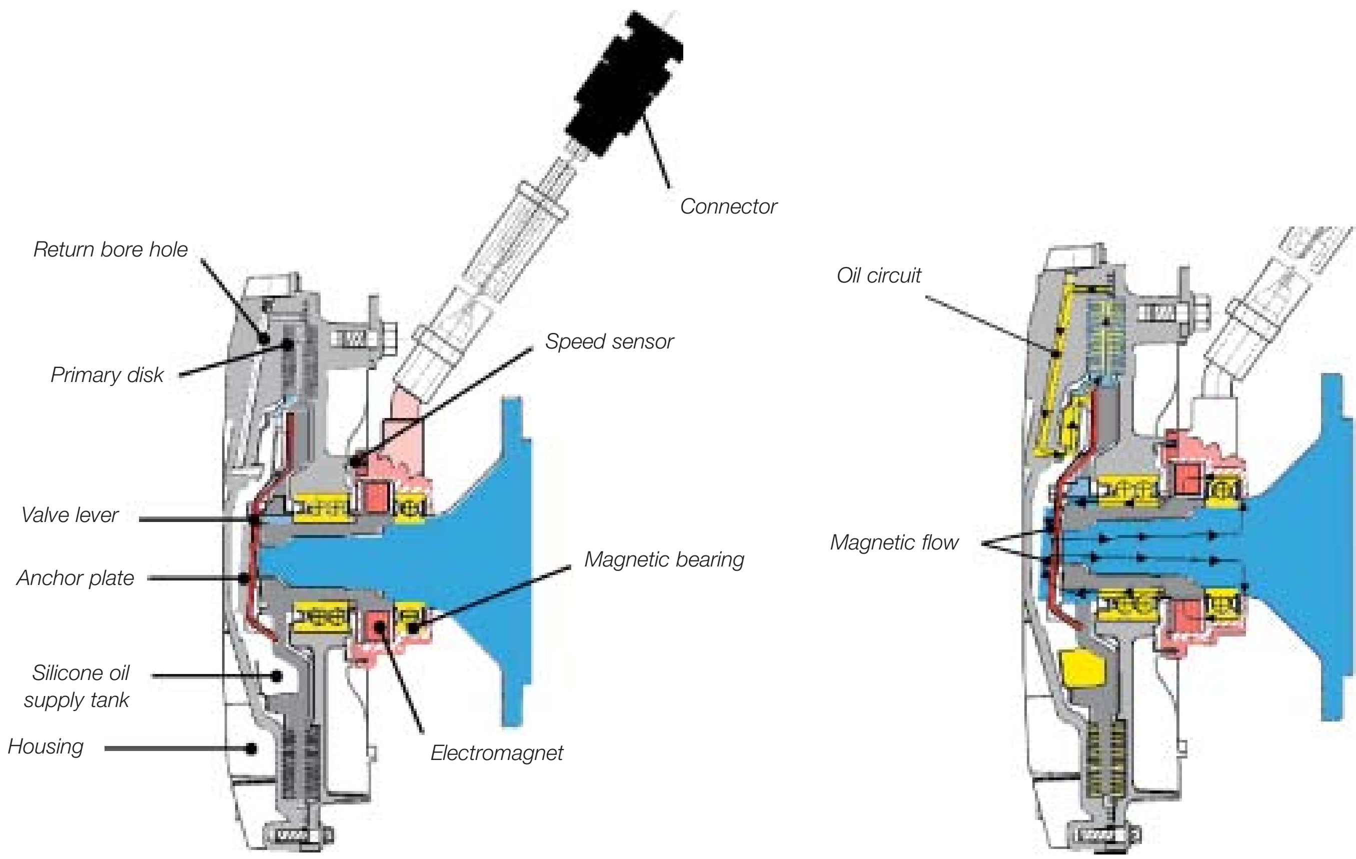
History:
Rigid (permanently driven) requires a lot of energy (BHP), is loud, has high consumption. In contrast, electrical fans (passenger car) consume less, are low noise and need less energy. The development goals were low consumption and low noise, e.g. noise reduction by means of shielded fan.

The further development into the electronic Visco® clutch yielded:

- Infinitely variable regulation
- Regulation by means of sensors
- Regulator processes data such as coolant, oil, charge air, engine speed, retarder, air-conditioning

This means demand-controlled cooling, improved coolant temperature level, low noise and reduced fuel consumption.
In passenger cars, the fans used to be 2-part, Visco® clutch and fan wheel were bolted together. Today, they are rolled and thus cannot be repaired.
The electronic Visco® clutch is at the moment installed in the Range Rover only.

Primary disk and flanged shaft convey the power of the engine. The fan is also rigidly connected to it. Circulating silicon oil effects power transmission between the two sub-assemblies. The valve lever controls the oil circuit between supply tank and working chamber. The silicone oil flows from the supply tank to the working chamber and back between two borings, the return bore hole in the housing and the feed bore hole in the primary disk. The valve lever controls the engine management by sending pulses to the magnet assembly. The Hall effect sensor determines the current speed of the fan and sends the information to the engine management. A regulator sends a cycled control current to the magnet assembly which controls the valve lever which in turn controls oil flow and oil quantity. The more silicone oil is in the working chamber, the higher the fan speed. If the working chamber is empty, the fan idles. The slippage of the drive is approx. 5%.



Electronically-controlled Visco® clutch

Types of construction are determined by the requirements and the desired cooling capacity. The latest and favourable design is the stack design which allows exact tailoring of installation space and cooling capacity.

5.1 Oil Cooling – Engine and Gearing

Cooling and fast heating up of the engine oil and the gear oil (e.g. automatic transmission) is guaranteed by coolers (engine or gearbox) installed in the water box. Design types are tubular and plate oil coolers.

Advantages:

- Cooling of thermally highly impacted oils
- Longer oil change intervals, longer engine life
- Reduced space consumption and weight due to full aluminium
- Compact design due to powerful stack plates with large surface cooling

5.2 Power-steering Cooling

The power-steering oil also needs to be cooled, because otherwise the efficiency of the power steering will be impaired and steering will be either sluggish or too easy-running.

Characteristics:

- Full aluminium with quick-coupling connections
- Pressure more than 8 bar with an oil entry temperature of between –40ºC and 160ºC
- Test pressure = 20 bar with a bursting pressure of 50 bar

5.3 Fuel Cooling

Mostly used in diesel engines where the fuel is cooled to lower the intake temperature in the case of pumping nozzle and common rail, because otherwise the fuel temperature excessively increases due to the high pressure. Too high fuel temperature impairs the engine performance due to early burning point in the combustion chamber.

5.4 Charge Air Cooling

The trend towards increasing engine performance and down-sizing leads to an ever greater share of turbo-charged engines for passenger cars. Today, engines are as a rule charged with cooled air. The higher charge air density achieved by this increases performance and efficiency of the engine. However, not just the share of turbo-charged engines is increasing, but, due to the continued requirements for reduced consumption and emissions, also the requirements on charge air cooling capacity which may be provided by cooling with a coolant instead of cooling with air. Because of the system costs, that technology was hitherto used only in the higher-priced passenger car segment. New developments also enable regulation of the charge air cooling which means that HC emissions can be reduced in addition to the reduction of the NO emissions and the efficiency of the exhaust gas final treatment can be improved. In addition to improved cooling capacity, another demand is made on charge air cooling: the temperature regulation of the engine process air by the regulation of the charge air cooling. The temperature regulation becomes necessary due to the constantly increasing requirements on exhaust gas final treatment where the temperature of the charge air plays an important part. Thus, the cooling of the charge air with coolant offers decisive advantages even in commercial vehicles.

Types:
Air cooled and coolant cooled. Direct and indirect.

Task:
Increase engine output by charging (more combustion air, greater oxygen share)

Advantages:
- Increased dynamic cooling capacity
- Improved engine efficiency thanks to increase in charge air density
- Reduced combustion temperature leading to improved emission values
- Less nitrogen oxides

5.4.1 Basics

Exhaust gas turbo-charging

The power output of a combustion engine depends on the amount of fuel burnt. 1 kg fuel needs 14.7 kg air to completely burn in an petrol engine, the so-called **stoichiometric relationship**. Therefore, an efficient way to increase the power output is the turbo-charging of combustion engines.

The power output of a combustion engine depends on the amount of fuel burnt.

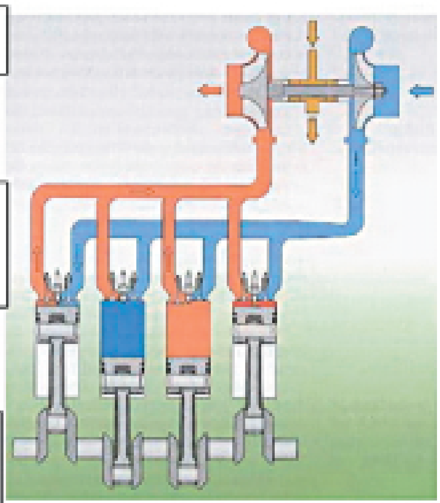
↓

1 kg fuel needs 14.7 kg air to completely burn in an petrol engine
Diesel engine > 14.7 kg air for 1 kg fuel

↓

Therefore, an efficient way to increase the power output is the turbocharging of combustion engines
Turbo-charged engine ⇔ naturally

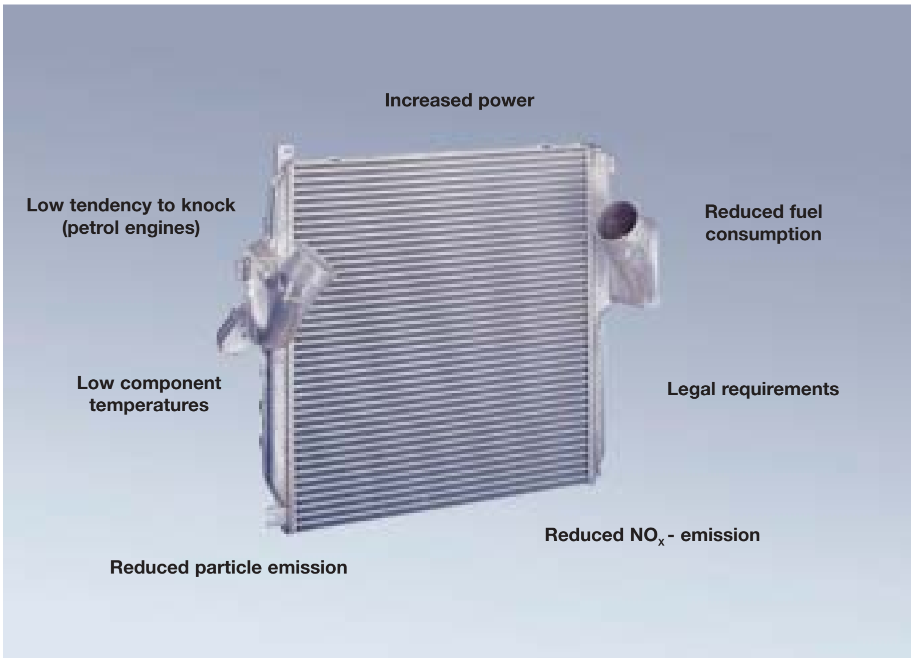
Turbo Charging



5.4.2 Requirements

Increased cooling capacity.

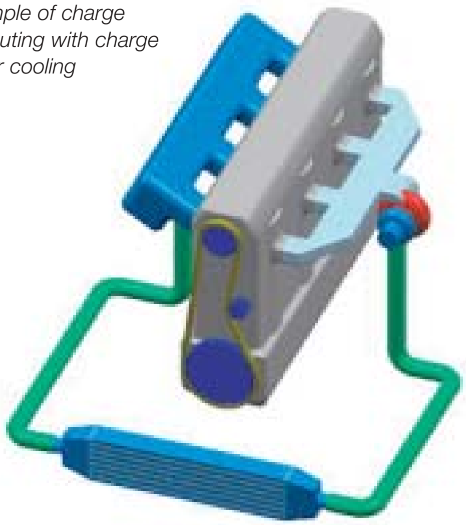
In passenger cars, the increasing demand for cooling capacity meets the increasing restrictions with regard to installation space in the engine compartment. Today, compact charge air coolers are still dominant. A solution to the problem of small installation depth is to enlarge the compact charge air cooler to a flat cooler installed in front of the coolant cooler, as is the standard in heavy commercial vehicles. Accordingly, that type of construction is increasingly used. However, this is not possible in many vehicles, because the installation space needed is already assigned or not available due to other requirements such as pedestrian protection. With two new systems, the conflict between installation space and performance requirements can be solved: charge air preliminary cooling and indirect charge air cooling.



5.4.3 Direct

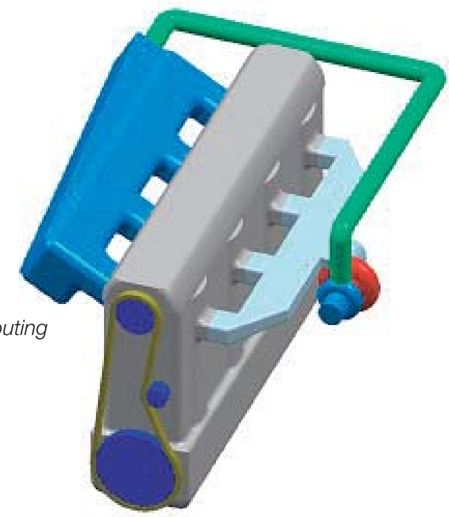
Charge air preliminary cooling or direct charge air cooling. Thanks to the use of the new Charge air preliminary cooler which is supplied with coolant from the engine circuit, a part of the charge air waste heat is shifted from the charge air cooler to the coolant cooler. In this way the additional charge air waste heat which is generated as a consequence of the performance increase is dissipated through the preliminary cooler and the concept of a block-type charge air cooler can be adhered to. The charge air preliminary, as in the case of a compact cooler, is located between turbo-charger and charge air/air cooler. Charge air preliminary cooling can considerably increase the performance of an existing concept.

Example of charge air routing with charge air/air cooling



Charge air/coolant as one component unit with air collector

Example of charge air routing with charge air/coolant cooling



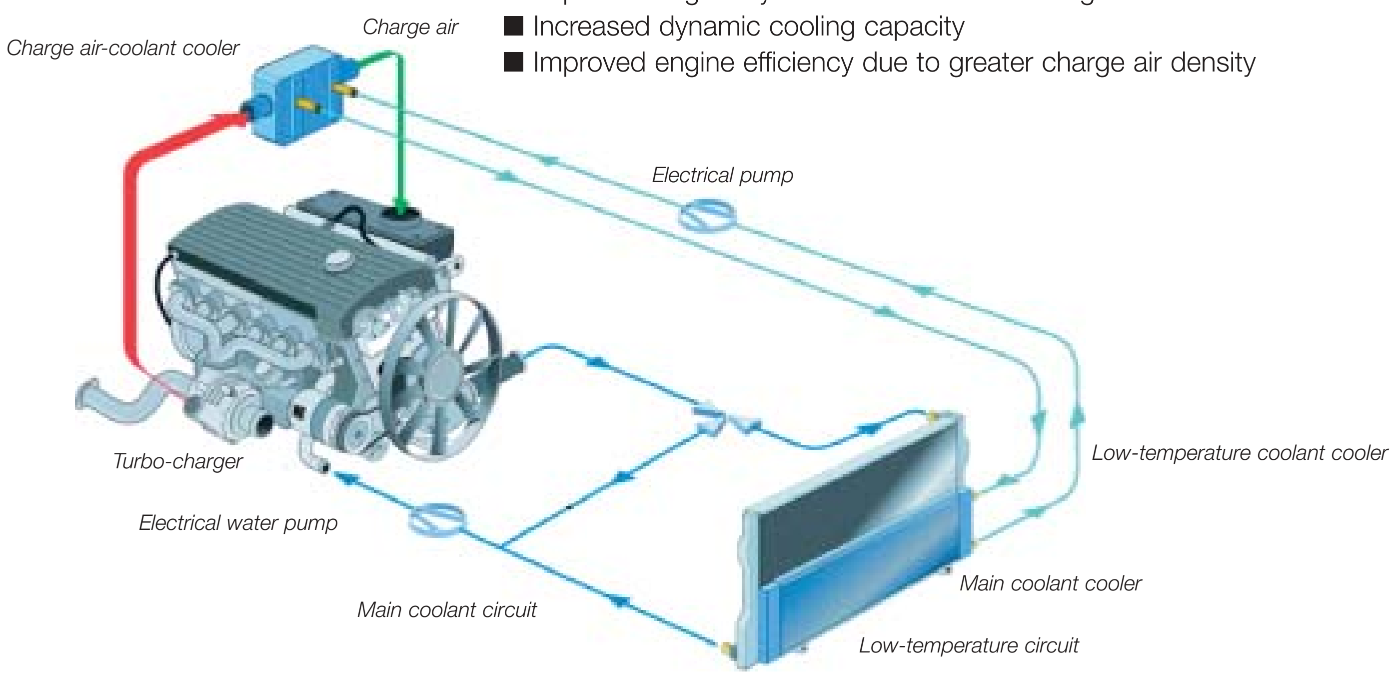
The design space required for a charge air/coolant cooler is around 40 – 60% of that for a charge air/air cooler.

5.4.4 Indirect

The second possibility to solve the conflict between installation space and performance requirements is indirect charge air cooling. In passenger cars, this cooling system usually comprises a complete coolant circuit which is independent of the engine cooling circuit. A low temperature coolant cooler and a charge air/coolant cooler are integrated in the circuit. The charge air waste heat is first transmitted to the coolant and then dissipated into the environment in the low-temperature coolant cooler which is located at the front end of the car where the charge air/air cooler is located in the case of usual air-cooled charge air cooling.
Since the low-temperature cooler requires considerably less space than a comparable charge air/air cooler, space is made available in the front end. Additionally, the voluminous charge air pipes from the vehicle front end to the engine are not needed. All in all, the packaging in the front end is considerably simplified which accordingly improves the cooling air flow through the engine compartment.

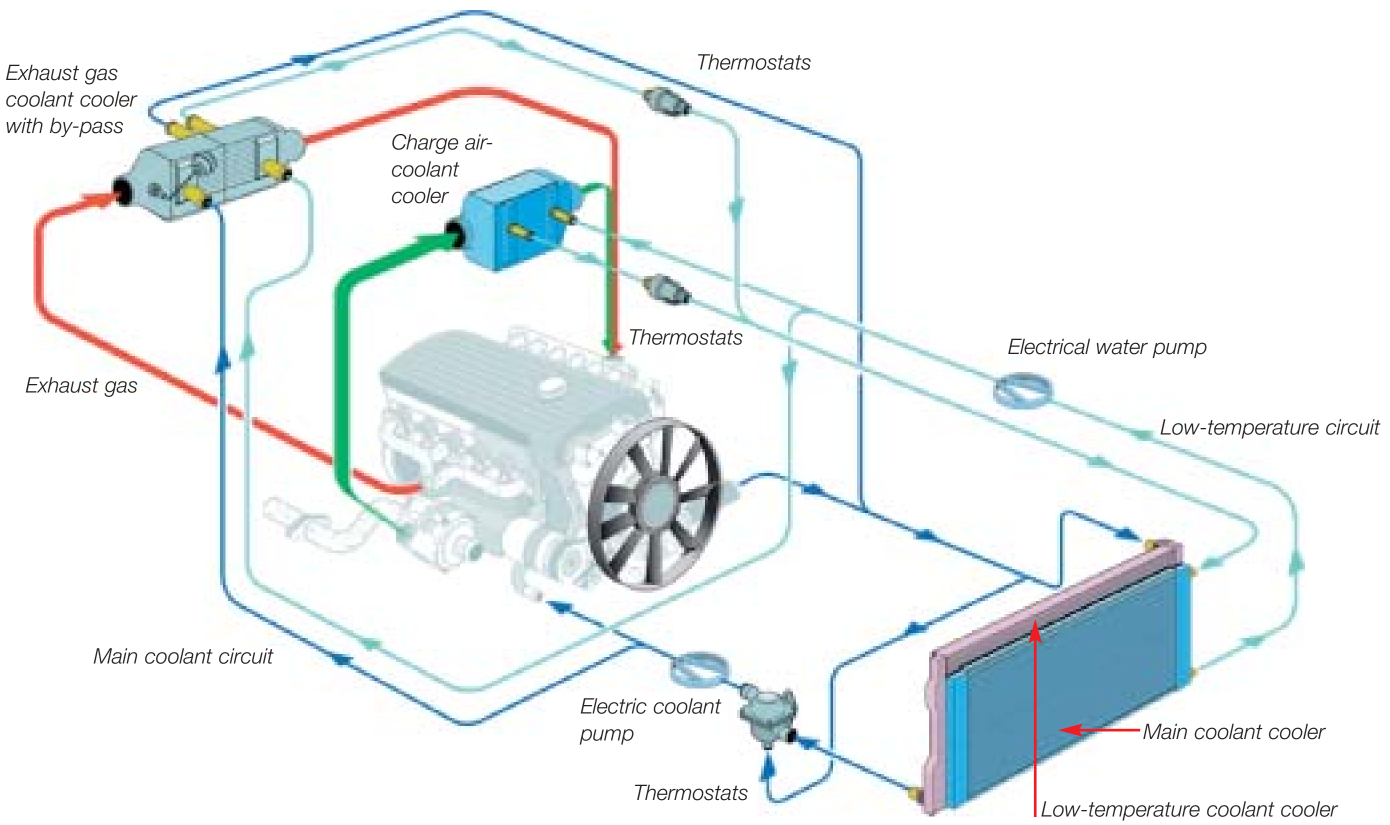
The following positive effects are provided by indirect charge air cooling compared to charge air preliminary cooling (direct):

- Considerably reduced charge air pressure drop
- Improved engine dynamics due to lower charge air volume
- Increased dynamic cooling capacity
- Improved engine efficiency due to greater charge air density



5.4.5 Temperature Regulation of the Engine Process Air

After a cold start and also at extremely low outside temperatures while driving it is reasonable to stop charge air cooling. Engine and catalytic converter thus reach their optimal operating temperature faster which reduces “cold start emissions“, mainly hydrocarbons (HC). In the case of a charge air/air cooler, this is only possible, at great expense, by means of a by-pass at the charge air end. In the case of indirect charge air cooling, however, a simple regulation of the coolant volume flow not only allows the cooling of the charge air to be stopped, but also to regulate its temperature. By linking the coolant circuit for the charge air cooling with that for the engine cooling and an intelligent regulation of the coolant throughputs, the indirect charge air cooling can be extended into a charge air temperature regulation. The charge air can be flown through either by the hot coolant of the engine circuit or by the cold coolant of the low-temperature circuit. Regulation of the charge air temperature is important to exhaust gas final treatment by particle filters and catalytic converters as both require a certain minimum exhaust gas temperature for optimal operation. For the catalytic converter, that temperature is identical with its light-off temperature, for the particle filter, the temperature is the regeneration temperature necessary for the combustion of the embedded soot. In partial load operation of the vehicle (city, stop and go), that exhaust gas temperatures are not always reached. In such cases, too, emissions can be reduced by stopping the cooling or even heating the charge air, as the exhaust gas temperature is increased by those measures at any rate. Both options can most easily be realised by indirect charge air cooling.



5.4.6 Modern Design for More Demanding Requirements

Performance comparison of the new concepts.
The performance increase to be achieved by the new “charge air preliminary cooling“ and “indirect charge air cooling“ concepts can be seen in a comparison to the prevailing compact charge air coolers and the more powerful flat charge air coolers. Charge air cooling is considerably improved. Additionally, the charge air pressure drop is substantially reduced with indirect charge air cooling.
Charge air coolers for higher stability requirements. Increasing requirements on the charge air coolers with regard to pressures and temperature require a new design and new materials for the cooler matrix and the air boxes. In passenger cars today, the charge air has a temperature of up to 150 °C and a pressure of 2.2 bar when it enters the cooler. In the future, temperatures and pressures will rise to 200 °C and 3 bar, respectively. To meet these requirements, the air boxes are made of thermally stable plastic or the charge air cooler and the air boxes are completely made of aluminium.

Even greater loads are expected in commercial vehicles. Compared to 200 °C and 3 bar today, the lower EURO-5 emission limit values are expected to lead to 260 °C and up to 4 bar. Through changes in the charge air cooler design, the tension level which adjusts itself due to the pressure load will be reduced so that the higher loads can be easily withstood. Due to its compact design, the coolant charge air cooler has further potential for increased stability.

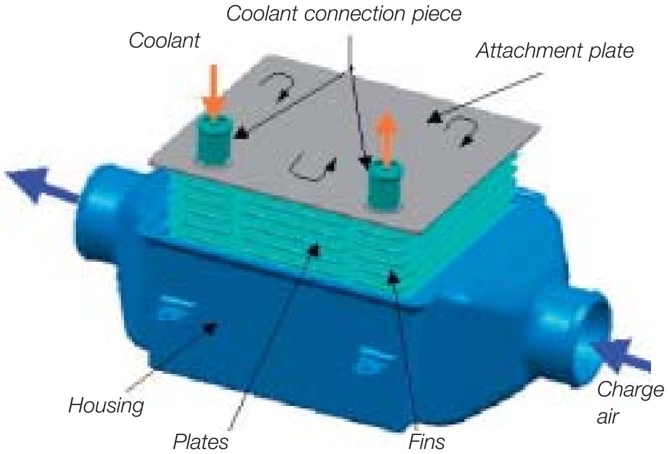
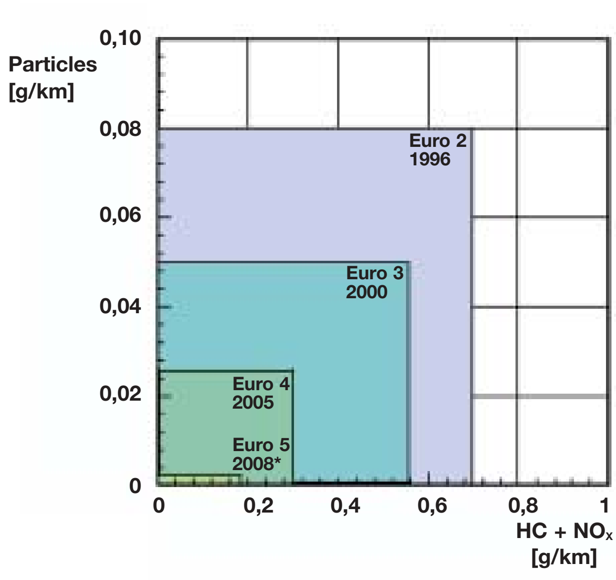


Plate design

Installation in cast or plastic housing

5.5 EURO 5 and Its Significance

For diesel passenger cars, Euro 5 means another substantial reduction of emissions compared to Euro 4: 40% for hydrocarbons (HC) and nitrogen oxides (NOx), 90% for particles. With regard to those goals, temperature regulation of the engine intake air will become ever more important. The intake air temperature management (ATM) developed by Behr reduces emissions at the point of origin, supports exhaust gas final treatment and facilitates the regeneration of the particle filter. Additionally, synergies between the sub-systems of the ATM mean that less installed cooling capacity will be required than for today's systems – saving fuel and installation space.



5.5.1 Functional Principle of the Intake Air Temperature Management (ATM)

The ATM consists of three sub-systems: the indirect charge air cooling, the cooled exhaust gas return and the engine cooling. The sub-systems are linked and regulated in such a way that the intake air can be cooled and heated and the combustion temperature can be lowered or raised. The temperature is lowered by cooling charge air and exhaust gas and by adding as much exhaust gas to the charge air as the engine's load condition allows and accordingly reducing the oxygen concentration in the cylinders.
To increase the combustion temperature, charge air and exhaust gas cooling are interrupted. Additionally, the charge air can be heated.

5.5.2 Reduction of Emissions

NOx: Since NOx formation is exponentially dependent on the combustion temperature, its reduction means a substantial reduction of NOx: approx. 10% per 10 °C temperature reduction; fuel consumption falls by between 0.5% and 1%.
HC and CO: When the engine is started cold, then the combustion temperature is in most cases low initially and combustion incomplete, with the consequence of high HC and CO formation. As the oxidation catalytic converter has not yet reached its operating temperature at that stage, emissions are generated. In certain situations (city driving in winter, stop-and-go), combustion and catalytic converter temperature may fall, even in normal driving, to an extent allowing HC and CO emissions to occur. In both cases a rapid increase of the combustion and thus exhaust gas temperature by the ATM reduces the generation of HC and CO and supports their conversion in the catalytic converter. The temperature is raised by interrupting the exhaust gas cooling. For this purpose, the exhaust gas cooler is equipped with an integrated by-pass and a switching flap. Roller-type test stand measurements on a turbo-charged 1.9-litre diesel engine have shown around 30% lower emissions of HC and CO during cold starts.

5.5.3 Regeneration of the Particle Filter

If the particle filter is full, the embedded soot must be burnt. To this end, the ATM also raises the exhaust gas temperature, which is usually below the soot ignition temperature of 550 °C. However, soot combustion may also be triggered by a reduction of the soot ignition temperature, e.g. by a fuel additive such as CER. A combination of both methods, increasing the exhaust gas temperature and reducing the soot ignition temperature, is advantageous: the amount of additive can be reduced, the admixture system can be simplified. However, if the temperature rise by the ATM is combined with after-injection, then an additional system for filter regeneration is, in most cases, not necessary.

5.5.4 Energy Saving

Various heat quantities are generated in the charge air and exhaust gas cooler, depending on the engine load. In the case of partial load in which the exhaust gas return rate may exceed 50 per cent, more coolant is needed in the exhaust gas cooler than in the charge air cooler. In some partial load points, e.g. 50 km/h at zero gradient, no charge air cooling at all is necessary and the entire cooling capacity can be supplied to the exhaust gas cooler. Under full load, however, practically the entire cooling capacity must be used for charge air cooling. Such demand-oriented distribution of the coolant flows may considerably reduced the installed cooling capacity and the installation space required, e.g. the radiator front surface by up to 10%.

5.5.1 Functional Principle of the Intake Air Temperature Management (ATM)

Indirect charge air cooling:
The charge air cooling increases the air density in the cylinder and lowers the combustion temperature. In the case of ATM, the charge air is not, as usual, cooled by air, but by a liquid coolant, a water-glycol-mixture as used for engine cooling. The charge air waste heat is first transmitted to the coolant and then dissipated into the ambient air in a low-temperature coolant cooler.

The advantages of indirect charge air cooling:
- Greater cooling capacity compared to conventional charge air/air cooling
- Higher cylinder filling rate due to the lower charge air pressure loss
- Shorter response time of the charge air cooling, because the charge air cooler is located near the engine

Cooled exhaust gas return:

This results in a reduction of the oxygen concentration in the cylinder, which means that temperature and speed of combustion are reduced. The intake air temperature management is suitable for both high pressure and low pressure gas return. In the case of high pressure exhaust gas return, the exhaust gas is taken off before the turbo-charger, cooled in the exhaust gas cooler and then added to the charge air. If the intake temperature is to be raised to improve exhaust gas final treatment, then the exhaust gas cooler is by-passed. The low pressure exhaust gas return is an option for the future in which the exhaust gas is taken out not before the exhaust gas turbo-charger, as in the case of the high pressure exhaust gas return, but after the exhaust gas turbo-charger and also the particle filter. The gas is then cooled and added to the charge air before the compressor of the turbo-charger.

Charge air heating:

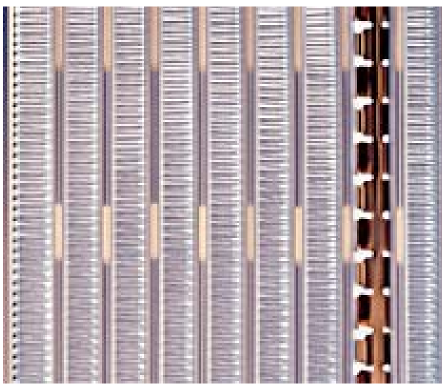
The ATM has four different ways to raise the intake air temperature: by stopping charge air cooling or exhaust gas cooling, both in combination and additionally by heating the charge air. For heating, a hot coolant partial flow is branched off from the engine cooling circuit and fed to the charge air cooler. In tests on an engine test stand with a 2-litre diesel engine with an indicated mean effective pressure of 2 bar, the exhaust gas temperatures were measured after the turbine which resulted from the variation of the intake air temperatures by means of the options specified above.
Interruption of the charge air cooling yielded the lowest exhaust gas temperature increase: approx. 6 °C. Heating the charge air with the engine coolant of a temperature of around 85 °C (thermostat temperature) raised the exhaust gas temperature after the turbine by around 16 °C. The max. potential based on heating is probably 20 °C. The highest temperature increase, namely approx. 57 °C, was achieved by interrupting the exhaust gas cooling (switchable exhaust gas cooler). If this is combined with the heating of the charge air, then the exhaust gas temperature can be raised by more than 70 °C. At an indicated mean effective pressure of 4 bar, the possible temperature raise is even 10 °C.

6 PTC Auxiliary Heater

Due to the high efficiency of modern direct injection engines, diesel and petrol, the engine waste heat is often not sufficient on cold days for fast heating of the passenger compartment nor for comfortable temperatures during city driving and stop and go. Driving safety is also impaired as the windscreen may fog. To eliminate the heating deficit, Behr is developing three kinds of auxiliary heaters: electric PTC heaters and CO2 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 and, additionally, the engine cold start phase is shortened. The heat pumps function on the basis of the new CO2 air-conditioning system. With the auxiliary heaters mentioned, EU specification EC 78317 and US specification FMVSS 103 for windscreen defrosting of vehicles with direct injection engines can be met without a problem.

PTC elements are non-linear ceramic resistors. “PTC“ stands for positive temperature coefficient, i.e. the electric resistance increases with the temperature of the element. However, this is not strictly true, because its resistance initially decreases with increasing temperature. In that range, the resistance curve has a negative temperature coefficient. Only after the minimal resistance is reached, the negative temperature coefficient changes to a positive one, i.e. the resistance at first decreases with increasing temperature and from around 80 °C increases strongly until the PTC material practically no longer draws additional current. At that point, the surface temperature of the PTC material is around 150 °C and that of the metal frame around 110 °C, provided no air is flowing through the PTC heater.

6.1 Structure and Function

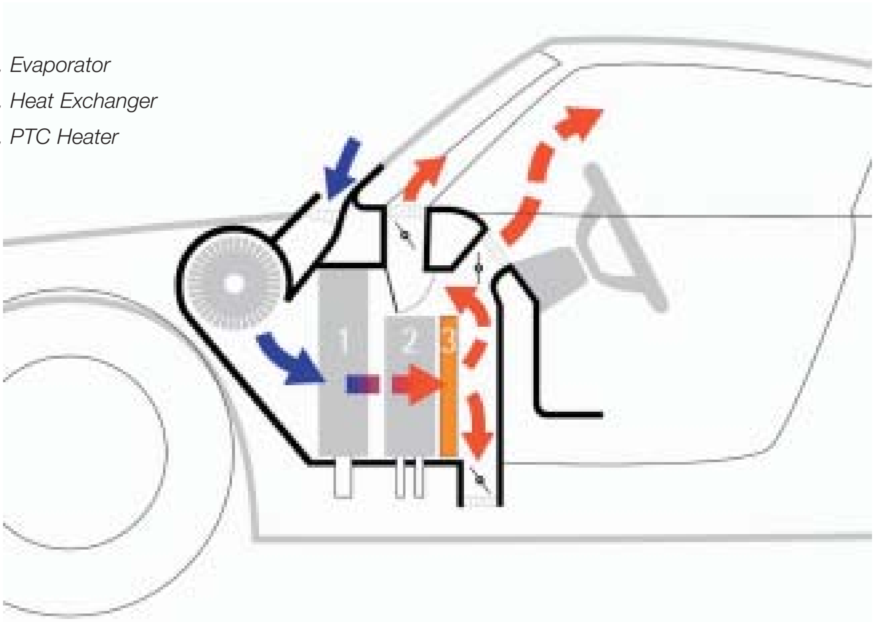


The PTC heater consists of several heating elements, an attachment frame, an insulating frame and the relays for the power electronics. The heating elements are composed of PTC ceramic stones, contact plates, connectors and aluminium corrugated ribs. The corrugated ribs increase the heat-dissipating surface of the contact plates. To increase heat transmission to the air, the corrugated ribs have slots called gills. The improved heat transmission allows a considerable reduction of the switch-on current raising compared to auxiliary heaters with corrugated ribs without gills. The advantage is that individual PTC strands can be connected more frequently, i.e. the heater can be operated with a higher power. The production know-how of the “gilling“ stems from cooler production. The auxiliary heater is arranged in the air-conditioning system in the air flow directly behind the conventional coolant/air heat exchanger, which means a minimisation of the installation space requirements. If outside temperatures are low and the engine is cold, the PTC heater is initially passed by cold air only or by air slightly heated by the exchanger. Temperature and resistance of the heating elements are low, but heating power is high. When the conventional heating starts, air temperature and resistance rise and the heating power decreases accordingly. At a surface temperature of a PTC heater flown through by 25 °C warm air, the hourly volume flow of air reached is 480 kg. At that air temperature, the heating systems has an average temperature of 50 °C.

6.2 Power and Spontaneity

The nominal resistance of the PTC material can be selected, with accordingly different current consumption and performance ratings. A low nominal resistance allows a high heating power in operation. The power of PTC heatings ranges from 1 kW to 2 kW. 2 kW is the power limit of a 12 V on-board power supply system (150 A at 13 V). Higher output would be possible in a 42 V on-board power supply system. Due to its low mass and the fact that the electrically generated heat is dissipated directly to the air, the PTC heating starts practically instantaneously. That high spontaneity is the characteristic feature of the PTC auxiliary heater. Since, additionally, the engine reaches its operating temperature faster due to the additional load on the generator, the conventional heating also starts earlier. This additional heating power is around two thirds of the power of the PTC heater. Practically, that heating power can be attributed to the PTC heating. The power of the PTC heater of the 220 CDI model of the new E-class is 1.6 kW. The PTC heater is integrated into the heating/air-conditioning module directly after the conventional heat exchanger.

Test example:
The vehicle was cooled down overnight to an oil sump temperature of –20 °C. Then it was run for 30 minutes in the climate wind tunnel in third gear at a speed of 32 km/h which is a very realistic average speed in city traffic. After 20 minutes, the average temperature in the passenger compartment with PTC heater was 18 °C, without just 10 °C. The “comfortable temperature“ of 24 °C was reached after 30 minutes with the PTC heater, without only after more than 50 minutes.



1. Evaporator
2. Heat Exchanger
3. PTC Heater

6.3 Operational Safety

The characteristic resistance curve of the PTC material prevents an overheating of the PTC heating. The temperature of the surface of the metal frame is always less than 110 °C. Moreover, the power of the PTC heating is reduced at higher blow-out temperatures of the heat exchanger. Power electronics enables regulation of the PTC heating in several stages or steadily, so it can be adjusted to the required heating power or the electric power available.

6.4 Control

The PTC heater is controlled either externally by relays or by an integrated control with power electronics. In the case of relay control, the vehicle manufacturer defines which and how many stages are added. In the case of control integrated in the auxiliary heater, a distinction is made between minimal and high functionality.
Minimal functionality means that the stages are added individually. The power electronics protect the auxiliary heater against overvoltage, short-circuit and polarity reversal. Diagnostics options are not provided with that type of control. The step-wise control has up to eight stages. The PTC heater used in the E-class has seven stages. Control is is dependent upon the current available and auxiliary heating need, i.e. the desired thermal comfort. Control with high functionality is control of the power electronics e.g. infinitely variable via the vehicle's LIN or CAN bus. This allows optimal use of the current provided by the on-board power supply for auxiliary heating in any situation.

In addition to protection against overvoltage, short-circuit and polarity reversal, the power electronics with high functionality includes protection of the PCB against overheating and a voltage controller. The control with high functionality can be diagnosed via an EPROM (Erasable Programmable Read Only Memory) and thus enables storage of the variants.

6.5 New Development

The new generation of PTC auxiliary heaters have been available since 2004 and are distinguished from their predecessors by reduced weight, reduced pressure drop (saves fan power) and reduced cost of production.

Technical features:

- Electric auxiliary heating; power 1 kW – 2 kW
- Heat source: self-regulating PTC ceramic stones, max. temperature at the surface of the ceramic material 150 °C if no air is flowing through the heating system
- Excellent heat transmission by corrugated rib technology with low pressure loss in the supply air
- Stepped or linear control via relays or control electronics
- High spontaneity and high efficiency
- Construction kit system enables optimal adjustment to existing installation space in the vehicle
- Absolutely safe operation, no hazard to neighbouring components due to inherent temperature limitation (PTC characteristics)
- Just slight increase of necessary blower power due to low pressure loss

7.1 Coolant, Anti-freeze Protection and Corrosion Protection

Different-colour coolants

Coolant protects against frost, corrosion, overheating and lubricates. Coolant is the generic term for the cooling liquid in the cooling system. Its task is to absorb the engine heat and dissipate it via the cooler. The coolant is a mixture of tap-water and anti-freezing compound (glycol/ethanol) mixed with various additives (bittering agent, silicate, antioxidant agents, foam inhibitors) and coloured. Bittering agents are to prevent the coolant from being drunk inadvertently. Silicates form a protective layer on the metal surfaces and prevent furring etc. Antioxidant agents prevent corrosion of components. Foam inhibitors suppress the foaming of the coolant. Glycol lubricates the components, keeps hoses and seals smooth and raises the coolant's boiling point.

The mixing ratio of water and antifreeze should be 60:40 to 50:50. This usually corresponds to anti-freeze protection at temperatures of –25 °C to –40 °C. The minimal mixing ratio should be 70:30 and the maximal 40:60. Further increase of the antifreeze share (e.g. 30:70) does not yield any lowering of the freezing point. On the contrary, undiluted antifreeze freezes already at around –13 °C and at temperatures of above 0 °C does not dissipate sufficient engine heat. The engine would overheat. As the boiling point of glycol is very high, the boiling point of the coolant can be raised to up to 135 °C by using the right mixing ratio. Therefore, a sufficient antifreeze share is important even in warm countries. Always follow the manufacturer's instructions. A typical composition could be 40%/60% or 50%/50% with the use of inhibited water (drinking water quality).

The coolant and its additives are subject to a certain wear, i.e. part of the additives will be used up in the course of some years. If for example the corrosion protection additives are used up, then the coolant gets brown. Therefore, some manufacturers specify a coolant change interval (e.g. Opel Sintra: every 5 years). However, the cooling systems of newer cars are increasingly filled with so-called long-life coolants (e.g. VW G12 Plus). Under normal circumstances (if no contamination occurs), the coolant needs not be changed (VW) or only after 15 years or 250,000 km (newer Mercedes models). As a rule, the coolant should be changed if pollution (oil, corrosion) has occurred and in the case of vehicles which are not equipped with long-life coolant. With regard to specifications, change interval, mixing ratio and miscibility of anti-freezing compounds, the vehicle manufacturer's instructions must be followed. Coolant must not get into the ground-water or be discharged via the oil separator. Coolant must be collected and disposed off separately.

7.2 Radiator Maintenance

The radiator needs not be serviced as protection inside and outside is provided already during production (Behr special). Cleaning by jet cleaner with low pressure from inside to outside as condensers.

7.3 Flushing the Cooling System

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

Contamination may be:
- Oil (defective cylinder head gasket)
- Rust (internal corrosion engine)
- Aluminium (internal corrosion radiator)
- Foreign particles (additives/sealant)
- Foreign particles (defective water pump)

Depending on the degree of soiling, the cooling system is cleaned with hot water or with a special flushing liquid. Depending on vehicle manufacturer and symptom, there are various approaches to flushing. Audi specifies a special flushing liquid for flushing if the coolant is rusty brown and the heating power is insufficient (e.g. Audi A6). For the multiple flushing process, the thermostat must be dismantled and the heating power must be measured before and after the flushing. With regard to its models Corsa, Vectra and Omega up to model year 1997, Opel/Vauxhall notes that a clogged radiator may be the cause of excessively high engine temperature. In that case, the system should be flushed with hot water (> 50 °C) and, in addition to the radiator, all coolant-contacting parts (heat exchanger, cylinder head etc.) should be replaced. The degree of contamination and the vehicle manufacturer's instructions thus specify the method and the flushing agent to be used. It should at any rate be observed that due to the design (e.g. flat tube) of modern cooling systems not all components can be flushed and therefore need to be replaced.

This goes in particular for the following components:
- Thermostat
- Radiator
- Electrical valves
- Closing cap
- Heat exchanger

If the coolant level in the expansion tank cannot be checked due to the contamination (oil, rust), then the tank must likewise be replaced. Thermostat and the closing cap should be replaced as a rule. If special cooling system cleaners are used, then care must be taken that they do not attack sealing materials and do not get into the ground-water or are disposed of via the oil separator. The cleaning agents must be collected together with the coolant and be disposed of separately. After flushing, the system must be filled with coolant following the vehicle manufacturer's instructions (specification, mixing ratio), bled and checked for function and tightness.

7.4 Bleeding the System When Filling It

Air in the cooling systems of motor vehicles has become a widespread problem. The air bubbles are caused by the positioning of the radiator or the expansion tank at the level of the engine or even below. Thus, the complete bleeding of the cooling system after repair or filling of the coolant may be a serious problem. Air in the cooling system considerably reduces the circula-

tion of the coolant and may lead to engine overheating and the consequent severe damage. Help is provided by the Hella Airlift System (art. no. 8PE 351 225-201).

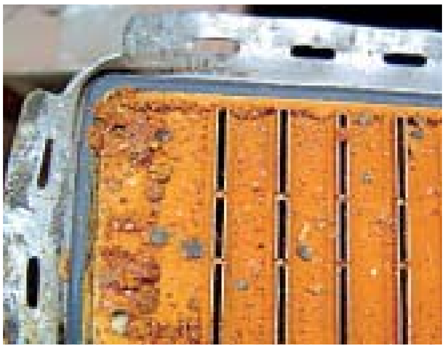
The system can be used to

- Eliminate air bubbles
- Check for leaks
- Quickly refill the cooling system

Airlift is connected to the radiator or the expansion tank using the adapter. Then, a compressed air hose is connected which you usually use to operate your pneumatic tools. Via a special valve, the cooling system is then evacuated and a high negative pressure generated. Then the suction hose is connected and the fresh water/antifreeze mixture is added to the cooling system. With the help of the manometer which measures the negative pressure, the integrity of the entire system can be checked at the same time.

7.5 Typical Damage
7.5.1 Radiator

The photos show typical damage due to various causes.



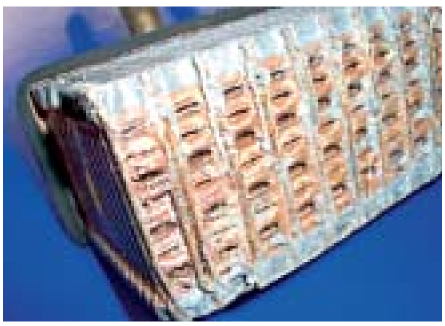
Deposits due to oil exiting stem from engine oil which gets into the coolant circuit due to a damaged cylinder head.

Furring due to the use of pure water (without coolant).

Additives cause reactions with the material and the coolant.

All faults cause reduced performance of the radiator.
Repair is not common in modern coolant coolers, because aluminium is difficult to weld and the small ducts might get clogged by the welding. Sealant must not be used, because it clogs and reduces the performance.

7.5.2 Heat Exchangers (Heating Radiators)



Furring and the use of sealants may clog the heat exchanger in the same way as the radiator. Such deposits can be removed by flushing with certain cleaning agents. Note the vehicle manufacturer's instructions.

7.6 Cooling System Check and Diagnosis

In the case of malfunction in the cooling system (e.g. heating doesn't heat, engine doesn't reach operating temperature or overheats) the problem can be found with easy means. Firstly, the cooling system should be checked for sufficient coolant, contamination, antifreeze and leaks. The V-belt or V-ribbed belt should also have sufficient tension. After that, trouble-shooting may be continued, depending on the symptom, by watching components or checking temperatures as follows:

7.6.1 Engine overheats:

- Is the temperature indicated realistic? (check cooling water temperature sensor and indicator instrument if necessary)
- Is the radiator or series-connected components (condenser) clean to guarantee unhindered air flow? (clean components if necessary)
- Does the radiator fan or auxiliary fan work? (check switch-on point, fuse, thermal switch, fan control unit, check for mechanical damage)
- Does the thermostat open? (measure temperature before and after the thermostat; if necessary, dismantle thermostat and check in water bath)
- Is the radiator clogged? (check temperature at entrance and exit of the radiator, check rate of flow)
- Does the water pump work? (check tight fit of pump wheel on the driving shaft (no slip))
- Does the pressure/suction relief valve of the radiator closing cap or of the expansion tank work? (use test pump if necessary, check whether the seal of the closing cap is damaged or missing)

7.6.2 Engine does not get warm:

- Is the temperature indicated realistic? (check cooling water temperature sensor and indicator instrument if necessary)
- Is the thermostat constantly open? (measure temperature before and after the thermostat; if necessary, dismantle thermostat and check in water bath)
- Does the radiator fan or auxiliary fan work permanently? (check switch-on point, thermal switch, fan control unit)

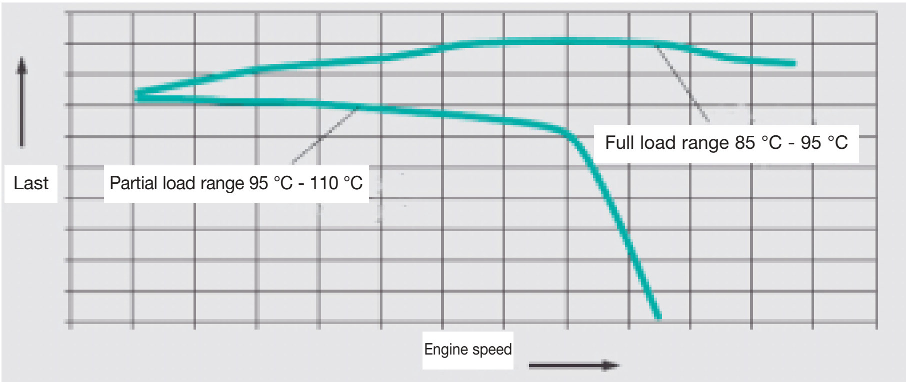
7.6.3 Heating not sufficiently hot:

- Does the engine reach operating temperature or the cooling water get warm? (if applicable, first check items at "Engine does not get warm")
- Does the heating valve open? (check electric control or bowden cable and valve)
- Is the heating radiator (heat exchanger) clogged? (check temperature at entrance and exit of the heat exchanger, check rate of flow)
- Does the flap position work? (check flap positions and limit stops, fresh air/circulating air function, air outlet nozzles)
- Does the passenger compartment blower work? (noise, fan stages)
- Is the passenger compartment filter soiled or rate of air flow decreased? (check passenger compartment filter, check fan ducts with regard to secondary air)

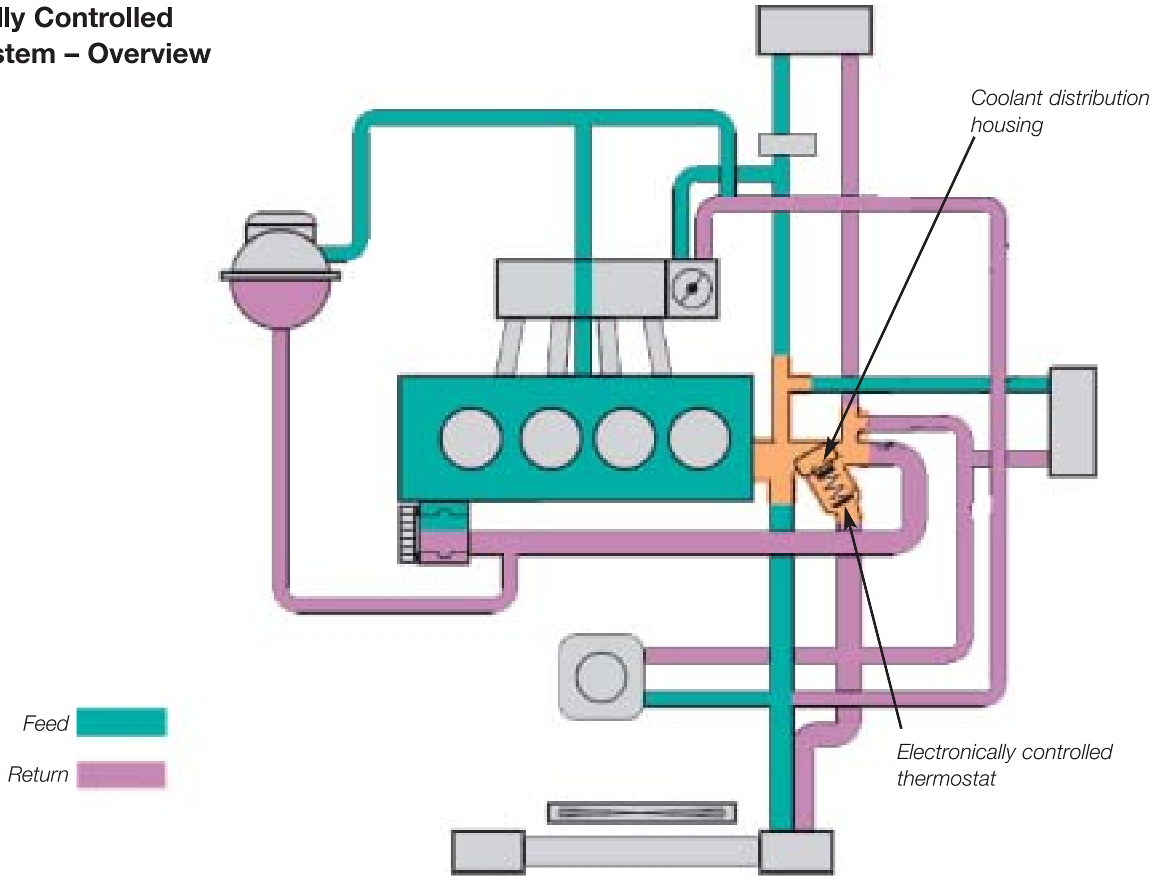
8.1 The Coolant Temperature Level

The engine's performance depends on its correct cooling. In the case of thermostat-controlled cooling, the coolant temperatures range from 95 °C to 110 °C in 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 favourable performance level which has a good effect on consumption and pollutants in the exhaust gas. Lower temperatures in the full load range improve performance. The air taken in is heated less which results in improved performance.

Coolant temperature level in dependence on engine load



8.2 Electronically Controlled Cooling System – Overview



The goal of the development of electronically controlled cooling was to adjust the engine operating temperature to a setting value in accordance with the load conditions.
An optimal operating temperature is adjusted via the electrically heated thermostat and the radiator fan stages based on engine characteristic maps stored in the engine control unit. Thus, the cooling can be adjusted in the entire performance and load condition of the engine.

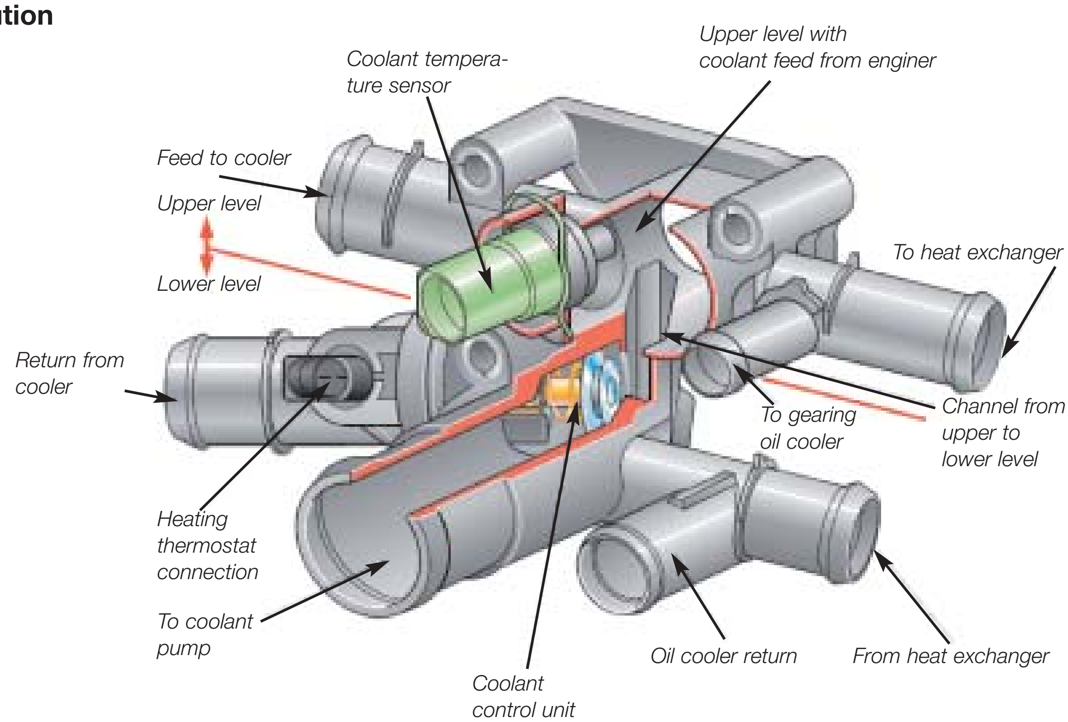
The advantages of the adjustment of the coolant temperature to the momentary engine operation condition are:

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

Changes compared to conventional cooling circuit:

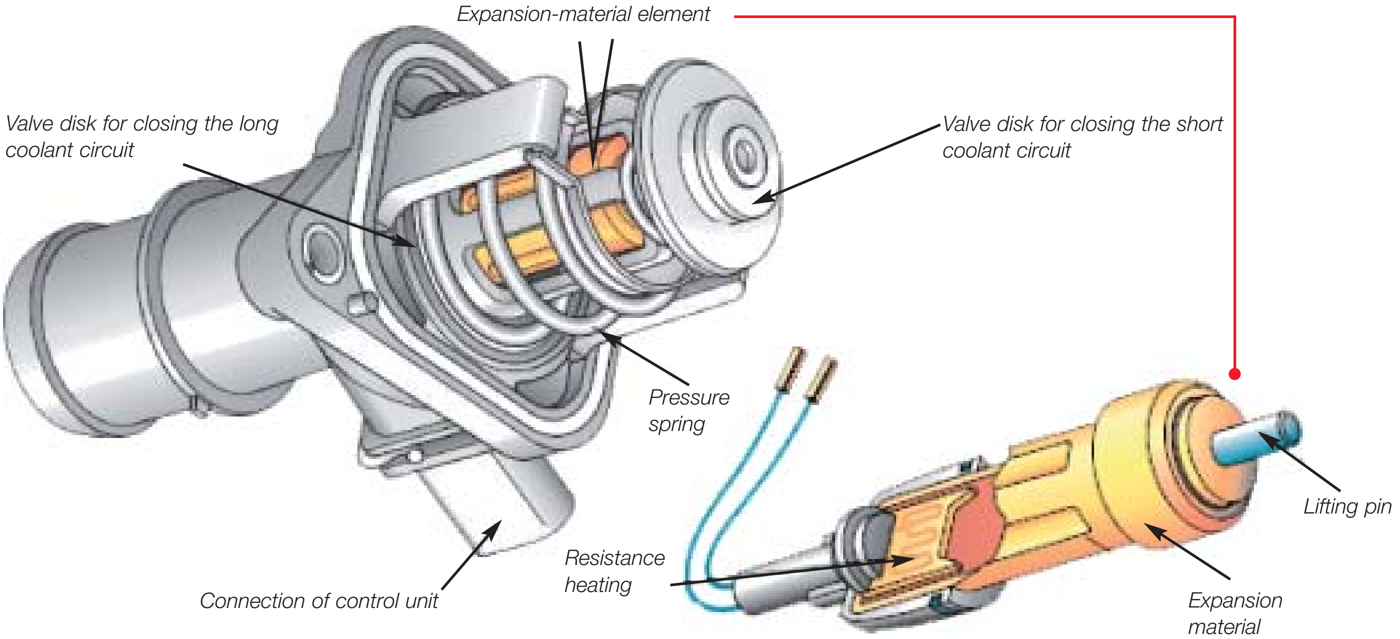
- Integration into the cooling circuit by minimal design changes
- Coolant distribution housing and thermostat are one component unit
- No coolant regulator (thermostat) at the engine block
- The engine control unit additionally contains the maps of the electronically controlled cooling system

8.3 Coolant Distribution Housing



The coolant distribution housing is installed at the cylinder head instead of the connecting sleeve. It should be looked at in two levels. From the upper level, the individual components are supplied with coolant. An exception is the feed to the coolant pump. The coolant return from the individual components is connected to the lower level of the distribution housing. A vertical channel connects upper and lower level. The thermostat opens/closes the vertical channel with its small valve disk. The coolant distribution housing is practically the distribution station of the coolant to the long and short cooling circuit.

8.4 Coolant Control Unit



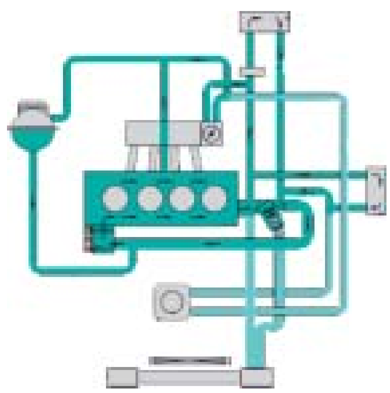
The functional components:

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

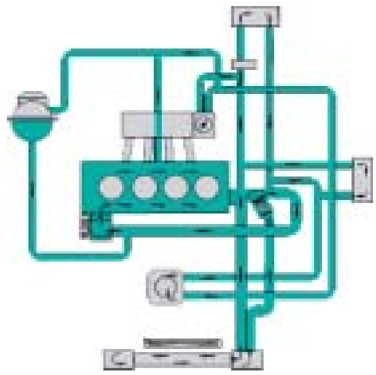
The function:

The expansion material thermostat in the coolant distribution housing is surrounded by coolant at all times. The wax element regulates without heating as before, but is dimensioned for a different temperature. The coolant temperature liquefies the wax and the wax expands. The expansion lifts the lifting pin. So, this is done normally without current flowing in accordance with the new temperature profile of 110 °C coolant temperature at the engine exit. A heating resistor is embedded in the wax element. If a current flows through the resistor, it heats the wax element additionally and the lifting, i.e. the adjustment, takes place not only in dependence on the coolant temperature, but in a manner specified by the map stored in the engine control unit.

8.5 Long and Short Coolant Circuit



As in the previous circuits, there are two circuits which are controlled in that case. The short circuit, for engine cold start and partial load and for fast heating of the engine. The map-controlled engine cooling does not yet act. The thermostat in the coolant distribution housing has blocked the return from the radiator and released the short path to the coolant pump. The radiator is not included in the coolant circulation.



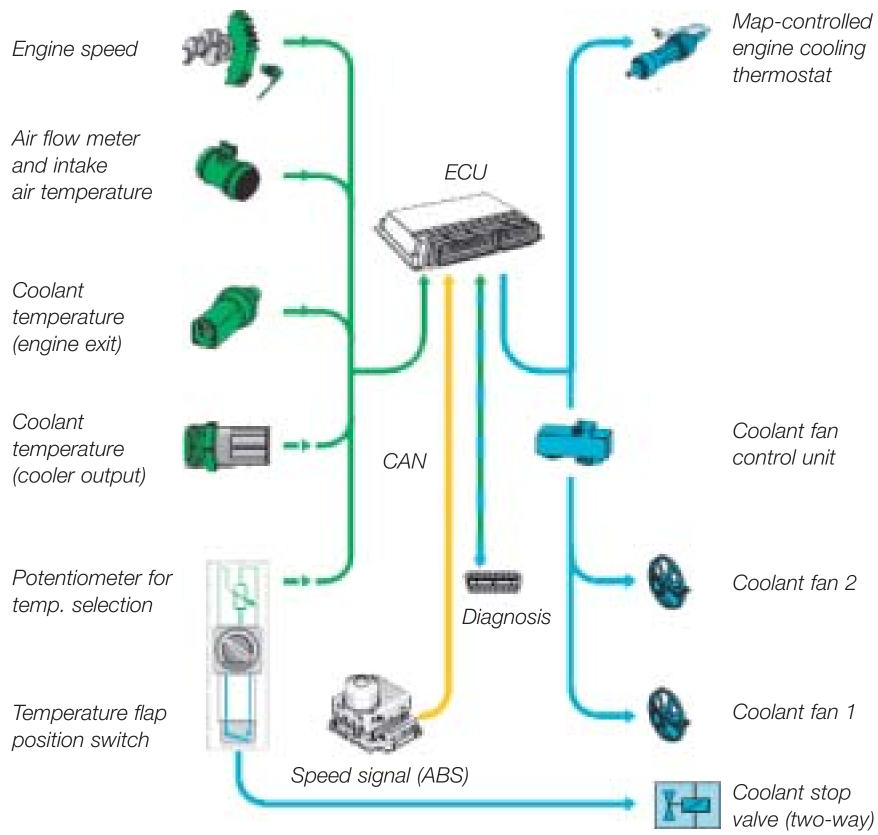
The long coolant circuit is opened either by the thermostat in the coolant regulator when a temperature of around 110 °C is reached or depending on load by the map. The radiator is now included in the coolant circulation. To support the cooling by the airflow or at idle speed, electric fans are switched on as required.

8.6 Electronic Control – Overview

The engine control unit was extended by the connections for the sensors and actuators of the electronically controlled cooling system:

- Current for thermostat (output)
- Radiator return temperature (input)
- Radiator fan control (2 outputs)
- Potentiometer at the heating regulator (input)

The sensors of the engine control are used to provide any other necessary information.

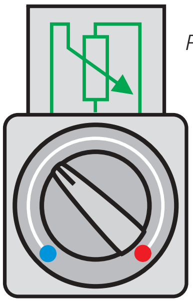


The functions regarding the map temperature are calculated every second and the system is regulated based on the function calculations:

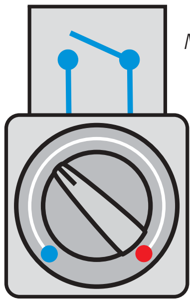
- Activation (current flow) of the heating resistor in the thermostat for map-controlled engine cooling to open the long cooling circuit (regulation of the coolant temperature)
- Control of the radiator fans to support fast decrease of coolant temperature

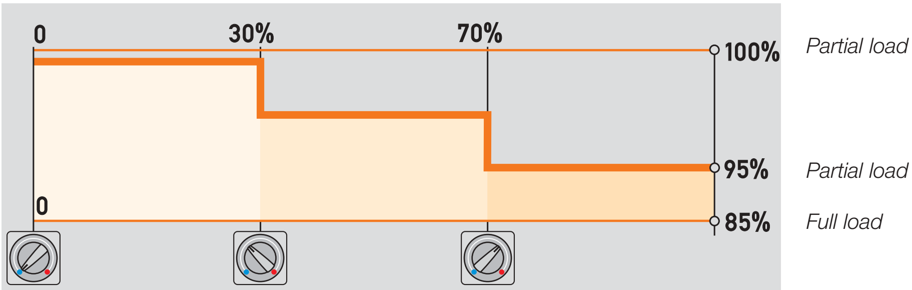
8.7 Regulation of the Coolant Temperature If Heating Is Desired

The coolant temperature may vary between 110 °C and 85 °C when driving between partial and full load. A temperature difference of 25 °C would become unpleasantly noticeable in the passenger compartment if the heating were switched on. The driver would constantly readjust. Due to the potentiometer, the electronics of the cooling system detects the driver's heating requirements and regulates the coolant temperature accordingly, e.g. position of rotating switch 70% = 95 °C coolant temperature.



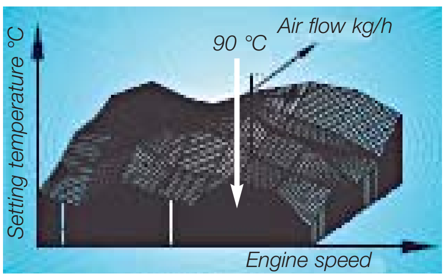
A micro-switch at the rotating switch for temperature selection opens as soon as the position "Heating off" is left. This controls a pneumatic two-way valve which in turn by negative pressure opens the coolant stop valve for the heat exchanger.



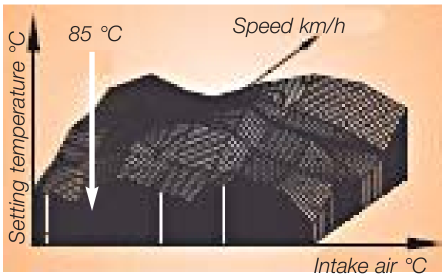


8.8 Map Setting Values

The thermostat for map-controlled engine cooling (long or short cooling circuit) is controlled by means of maps in which the temperature setting values are stored. The decisive data is the engine load. The coolant temperature to be adjusted results from the load (air flow) and the engine speed.



Temperature setting values are stored in a second map, depending on speed and intake air temperature. The coolant temperature to be set results from this. The lower value from a map comparison 1 to 2 is used as setting value and the thermostat is adjusted accordingly. The thermostat becomes active only if a temperature threshold is exceeded and the coolant temperature is just below the setting value.



8.9 Coolant Temperature Sensor

Engine exit coolant temperature sensor

The temperature sensors are NTC sensors. The coolant temperature setting values are stored in maps in the engine control unit. The actual coolant temperature values are recorded in two places in the cooling circuit and sent to the control unit in the form of voltage values.

Coolant actual value 1 – directly at the exit of the coolant at the engine in the coolant distributor.

Coolant actual value 2 – at the radiator before the exit of the coolant from the radiator.

Signal use: The comparison between the setting temperatures stored in the maps with the actual temperature 1 yields the on/off ratio of the current supply of the heating resistance in the thermostat. The comparison between the coolant actual values 1 and 2 is the basis for the control of the electric fans for coolant.

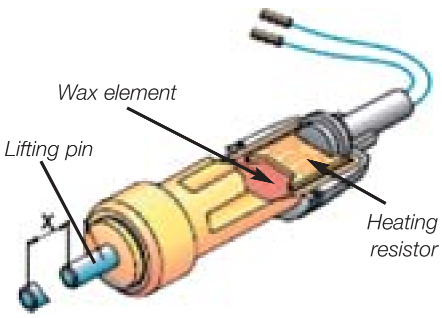
Substitute function: If the sensor for the coolant temperature (engine exit) fails, then the coolant temperature regulation is continued with a defined substitute value of 95 °C and fan stage 1 is permanently active.
If the sensor for the coolant temperature (radiator exit) fails, then the regulation remains active and fan stage 1 is permanently active.

If a certain temperature threshold is exceeded, then fan stage 2 is activated. If both sensors fail, then maximal voltage is applied to the heating resistor and fan stage 2 is permanently active.

8.10 Map-controlled Thermostat

A heating resistor is embedded in the wax element of the expansion material thermostat. The resistor additionally heats the wax which expands and thus creates the lift X of the lifting pin in accordance with the map. The lift X effects a mechanical adjustment of the thermostat. The heating is controlled by the engine control unit in accordance with the map, by means of a PWM (pulse width modulation) signal. The resulting heating depends on pulse width and time.

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



No operating voltage:
- Regulation with expansion element only
- Fan stage 1 permanently active

The thermostat heating is not used to heat the coolant, but for defined heating to trigger the thermostat to open the long coolant circuit.

At standstill or starting of the engine, no voltage is applied.

8.11 Summary

Modern cooling systems have become much more technical, as is the case with all other systems in the car today. In order to be able to understand and diagnose modern thermo-management systems, basic knowledge is no longer sufficient. What is needed is system competence and the ability to think logically.

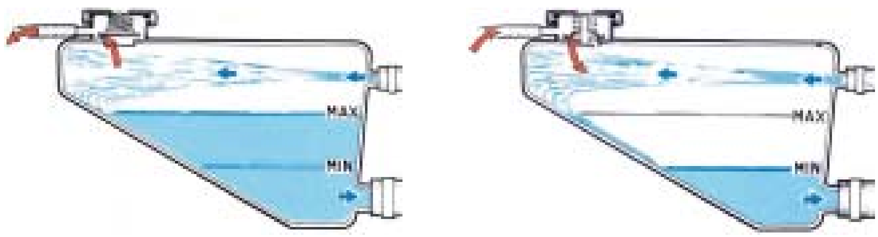
Engine cooling was yesterday. Today we have thermo-management.

9.1 Expansion tank
General points

Design/Function

The expansion tank in the cooling system is usually made of plastic and is used to trap the expanding coolant. It is normally installed in such a way that it represents the highest point in the cooling system. It is transparent to allow the coolant level to be checked, and has "min" and "max" markings. In addition, an electronic level sensor can be installed. Pressure compensation in the cooling system is achieved by means of the valve in the lid of the expansion tank.

An increase in coolant temperature leads to an increase in pressure in the cooling system since the coolant then expands. This increases the pressure in the expansion tank, opening the pressure control valve in the lid and allowing air to escape.



When the coolant temperature is normalised, a vacuum is created in the cooling system. Coolant is sucked back out of the bottle. This in turn creates a vacuum in the bottle. As a result, the vacuum compensation valve in the lid of the expansion tank is opened. Air flows into the bottle until the pressure has been balanced.

Effects of failure

A faulty expansion tank or a faulty lid can be noticed as follows:
- Loss of coolant (leak) at various system components or the expansion tank itself
- Increased coolant and/or engine temperature
- Expansion tank or other system components are cracked/burst

The following can be considered as possible causes:
- Excess pressure in the cooling system on account of a faulty valve in the lid
- Material fatigue

Troubleshooting

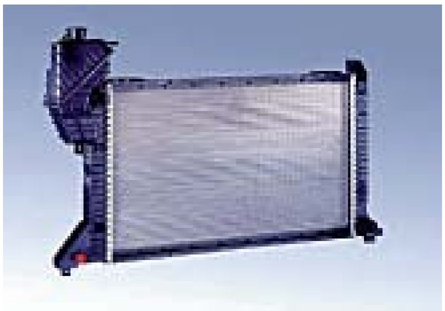
Test steps towards recognising faults:
- Check the level of coolant and the antifreeze content
- Check whether the coolant is dyed/soiled (oil, sealant, lime deposits)
- Check thermostat, radiator, heat exchanger, hose lines and connections for leaks and function
- Burst test the cooling system if necessary (pressure test)
- Make sure no air is trapped in the cooling system, vent the system according to vehicle manufacturer's instructions if necessary

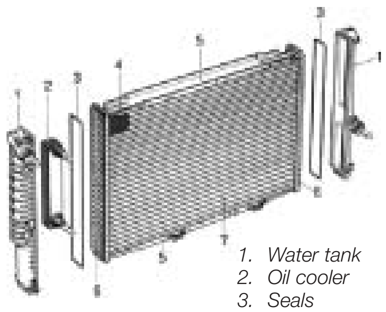
If all the above points are carried out without complaint, the lid on the expansion tank should be replaced. It is very difficult to test the valve on the expansion tank lid.

9.2 Coolant radiators General points

Coolant radiators are installed in the air flow at the front of the vehicle, with different designs available. They have the task of dissipating heat produced by combustion in the engine and absorbed by the coolant. Other coolers, e.g. for automatic transmission, can be found in or on the coolant radiator.

Structure/function





1. *Water tank*
2. *Oil cooler*
3. *Seals*
4. *Cool ribs (network)*
5. *Side panels*
6. *Bottom*
7. *Cooling pipe*

The most important component of a coolant module is the coolant radiator. It comprises the radiator core and water tank with all the necessary connections and attachment elements. The radiator core itself is made up of the radiator network – a pipe/rib system – the pipe bottoms and the sides.

Conventional coolant radiators have a coolant box made of glass fibre reinforced polyamide which has a seal fitted and is beaded before being placed on the pipe bottom. The current trend is moving towards all-aluminium radiators, which stand out due to reduced weight and a slimmer design. In addition, they are 100 % recyclable.

The coolant is cooled down by means of the cooling ribs (network). The external air flowing through the radiator network withdraws heat from the coolant. In terms of design, a distinction is made between downflow and crossflow radiators. In the case of downflow radiators, the water enters the radiator at the top and emerges at the bottom. In the case of crossflow radiators, the coolant enters at one side and emerges at the other. If the input and output pipes of the crossflow radiator are on the same side, the water tank is divided. Coolant then flows through the radiator, in opposite directions in the upper and lower parts. Crossflow radiators have a lower design and are used particularly in passenger cars.

Effects of failure

Limescale deposits

A faulty radiator can become noticeable as follows:
- Poor cooling performance
- Increased engine temperature
- Permanent radiator fan operation
- Poor air conditioning system performance

The following can be considered as possible causes:
- Loss of coolant caused by damage to the radiator (gravel throw, accident)
- Loss of coolant through corrosion or leaky connections
- Poor heat exchange caused by external or internal impurities (dirt, insects, limescale deposits)
- Soiled or old coolant

Troubleshooting

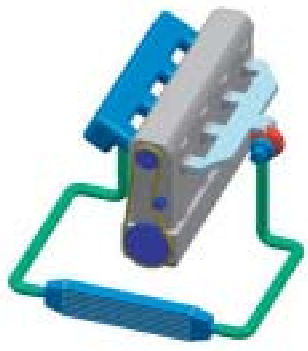
Deposits caused by oil leaking

Test steps towards recognising faults:
- Check the coolant radiator for outer soiling, clean with reduced compressed air pressure or a water jet if necessary. Do not get too close to the radiator lamellas
- Check the radiator for external damage and leaks (hose connections, beading, lamellas, plastic housing)
- Check coolant for discolouring/soiling (e.g. oil caused by faulty gasket) and check anti-freeze content
- Check coolant flow (blockage through foreign matter, sealing agents, limescale deposits)
- Measure the temperature of the coolant as it enters and leaves the radiator with the aid of an infrared thermometer (e.g. from Behr Hella Service, part no.: 8PE 351 228-031)

9.3 Intercoolers General points

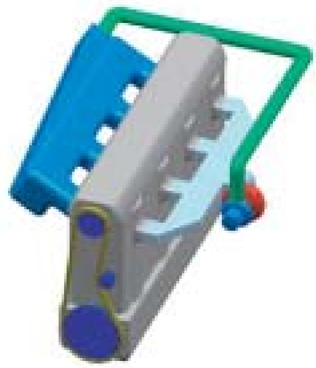
Increase in power over the whole speed range, low fuel consumption, improved engine efficiency, reduction of emission values, less thermal stress for the engine - there are numerous reasons to cool the combustion air of supercharged engines with intercoolers. Basically, a distinction must be made between two types of cooling. Direct charge air cooling, where an intercooler is installed in the vehicle front-end area and is cooled by environmental air (wind blast), and indirect charge air cooling, where coolant flows through the intercooler and discharges heat.

Structure/function



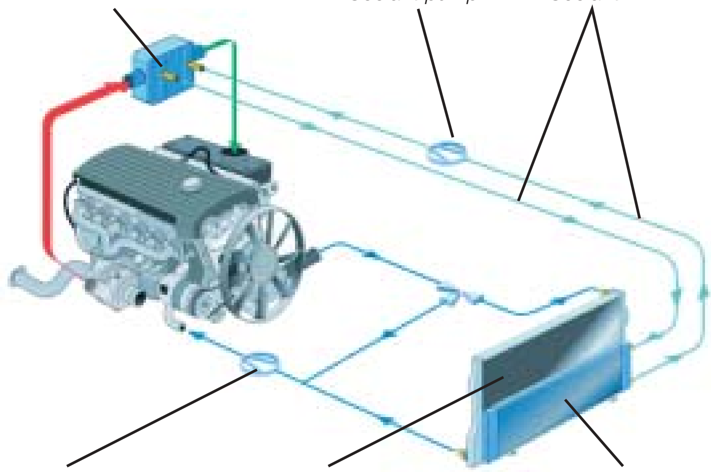
Direct charge air cooling

In terms of structural design, the intercooler corresponds to the coolant radiator. In the case of an intercooler, the medium to be cooled down is not coolant, but rather compressed hot air (up to 150 °C) coming from the turbocharger. Basically, heat can be withdrawn from the charge air by outside air or the engine coolant. The charge air enters the intercooler and, in the case of direct charge air cooling, has the wind blast flow through it and has cooled down by the time it reaches the engine intake tract. In the case of a coolant-cooled intercooler, the cooler can be installed in almost any position, with the smaller design volume representing a great advantage. Thus, for example, in the case of indirect charge air cooling, the coolant-cooled intercooler and the intake tract can form one unit. Without an additional cooling circuit, however, the charge air can only be reduced to near the coolant temperature.



Indirect charge air cooling/ intake manifold with integrated intercooler

With the aid of a separate intercooler coolant circuit independent of the engine coolant circuit, the efficiency of the engine can be further increased by increasing the air density. A low-temperature coolant radiator and a charge air coolant radiator are integrated in this circuit. The waste heat from the charge air is first transferred to the coolant and then dissipated to the environmental air in the low-temperature coolant radiator. The low-temperature radiator is housed in the vehicle front-end. Since the low-temperature radiator requires significantly less space than a conventional air-cooled intercooler, this solution creates free space in the front-end. In addition, the voluminous charge air lines are no longer required.



Effects of failure

A faulty intercooler can become noticeable as follows:
- Poor engine performance
- Loss of coolant (in the case of coolant-cooled intercooler)
- Increased pollutant emission
- Increased fuel consumption

The following can be considered as possible causes:
- Damaged or blocked hose/coolant connections
- Loss of coolant or secondary air due to leaks
- Outer damage (caused by gravel throw, accident)
- Reduced air flow (dirt)
- Lack of heat exchange due to inner soiling (corrosion, sealing agent, lime-scale deposits)
- Failure of the coolant pump (in the case of low-temperature coolant radiators)

Troubleshooting

Test steps towards recognising faults:
- Check coolant level
- Check coolant for soiling/discolouring and anti-freeze content
- Watch out for external damage and soiling
- Check system components and connection elements (hose connections) for leaks
- Check coolant pump
- Check fans and auxiliary fans
- Check the flow rate (blockage due to foreign materials, corrosion)

9.4 Oil coolers General points

The cooling of oils under a high thermal load (engine, gear, steering aid) by oil coolers or the guarantee of an almost constant temperature results in significant advantages. The intervals between oil changes can be extended and the service life of various components increases. Depending on the requirements, oil coolers are located in/on the radiator or directly on the engine block. A basic distinction is made between air-cooled and coolant-cooled types of oil cooler.

Design/Function


Various oil coolers


Stack-disc oil coolers

These days, conventional cooling is no longer sufficient for vehicle units which are under a high load. Thus, for example, the engine oil is cooled extremely irregularly, since it is dependent on outdoor temperature and the wind blast. Air-cooled oil coolers which are located in the air stream at the front end of the vehicle, contribute to sufficient cooling of the oil temperature. Liquid-cooled oil coolers are connected to the engine coolant circuit and provide optimum temperature regulation. In this case, coolant flows through the oil cooler. When the engine is hot, the coolant withdraws the heat from the oil, thus cooling it down. When the engine is cold, the coolant warms up more quickly than the oil and thus dissipates heat to the oil. This helps the oil to reach its operating temperature more quickly. Quick achievement of the operating temperature or the maintenance of a constant operating temperature is particularly important in the case of automatic transmission and steering aids. Otherwise, steering could become too stiff or too easy-running, for example. Today, pipe coolers are being replaced more and more by compact all-aluminium stack-disc coolers. These offer greater large-area cooling despite reduced design space and can be attached at a wide variety of points in the engine compartment.

Effects of failure

A faulty oil cooler can become noticeable as follows:
- Poor cooling performance
- Oil loss
- Increased oil temperature
- Soiled coolant

The following can be considered as possible causes:
- Poor heat exchange caused by external or internal impurities (insects, dirt, oil sludge, corrosion)
- Oil loss through damage (accident)
- Oil penetrating the cooling system (inner leak)
- Loss of oil through leaky connections

Troubleshooting

Test steps towards recognising faults:
- Check oil and coolant levels
- Check oil cooler with regard to outer soiling, damage (hairline cracks)
- Check coolant for soiling/discolouring and anti-freeze content
- Watch out for external leaks (connections)
- Check the flow rate (blockage due to foreign materials, corrosion, oil sludge etc.)

9.5 PTC booster heater General points

Fig. 1

On account of the high efficiency of modern, direct injection engines (e.g. TDI), dissipated heat is no longer sufficient for heating up the inside of the vehicle quickly on cold days. PTC booster heaters (Fig. 1), which are installed in the direction of travel in front of the heat exchanger, make it possible to heat up the vehicle interior more quickly. They are made up of several temperature-dependent, electrically controlled resistors. Energy is taken from the vehicle wiring system without delay and dissipated into the inside of the vehicle directly as heat via the blower air flow.

Design/Function

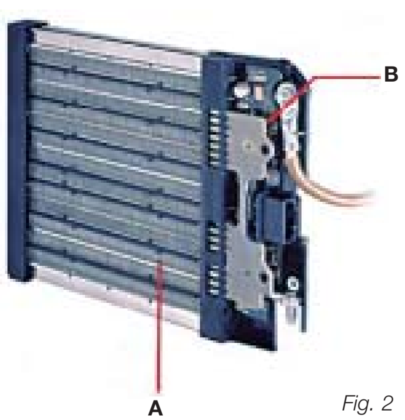
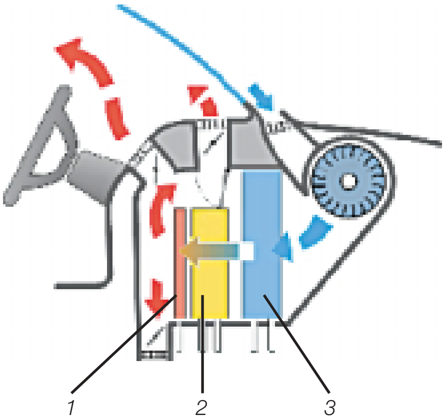


Fig. 2

PTC elements are non-linear ceramic resistors. "PTC" stands for "Positive Temperature Coefficient", i.e. the electrical resistance increases as the temperature of the element increases. This is not absolutely correct, however, since it initially drops as temperature increases. The resistance curve has a negative temperature characteristic in this range. The negative characteristic only changes into a positive one once the minimum resistance has been reached, i.e. as temperature increases, the resistance is first reduced and then increases quickly from about 80 °C, until the PTC heating elements can practically no longer absorb additional current. At this point, the surface temperature is around 150 °C and the temperature of the metal frame around 110 °C if no air is flowing through the PTC heater.
The PTC heater is made up of several heating elements (Fig. 2, Pos. A), an attachment frame, an insulation frame and the relay or electronic power module (Fig. 2, Pos. B).

The heating elements comprise PTC ceramic bricks, contact plates, connections and aluminium corrugated fins. The corrugated fins increase the area of the contact plates dissipating heat. To increase heat transfer on the air-side, the corrugated fins have slits, so-called "gills". The improved heat transfer allows the increase in the level of current required to switch on the heater to be significantly reduced compared to booster heaters without "gill" corrugated fins. This means that individual PTC strands can be switched on more often, allowing the heater to be operated at higher power. The production know-how for these "gills" comes from radiator production.



1 = PTC booster heater
2 = Heat exchanger
3 = Evaporator

The booster heater is located in the heating/air conditioning unit, in the air flow directly after the conventional heat exchanger, which reduces design space requirements to a minimum. At low outdoor temperatures and with the engine cold, only cold air or air heated slightly by the heat exchanger initially flows through the PTC heater. Temperature and resistance of the heating elements are low, but the heating power is high. When the conventional heating reacts, air temperature and resistance increase and the heating power decreases accordingly. A volume flow of approx. 480 kg of air per hour is achieved when air at 25 °C flows through the PTC heater. At this air temperature, the heating network assumes an average temperature of 50 °C.

The nominal resistance of the PTC elements can be chosen individually according to current consumption and power. A low nominal resistance allows a high heating power during operation. The power 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) has been reached. Higher capacities would be possible with a 42 V vehicle wiring system. The low mass and the fact that the electrically produced heat is dissipated directly to the air flow leads to the PTC heater reacting practically immediately. This high degree of spontaneity is the typical feature of the PTC booster heater. In addition, since the engine reaches operating temperature more quickly as well on account of the additional load caused by the generator, the conventional heating system also reacts more quickly. This additional heating power corresponds to around two thirds of the power of the PTC heater. This heating power can practically be accounted to the PTC heater.

The characteristic resistance curve of the PTC elements prevents the PTC heater from overheating. The temperature at the surface of the metal frame is always less than 110 °C. In addition, the power of the PTC heater is reduced at higher blow-out temperatures of the heat exchanger. An electronic power module allows the PTC heater to be regulated in several stages or infinitely so that it can be adapted to the required heating power or the electrical power available.
The PTC heater is triggered either externally by means of a relay or through an integrated control unit with electronic power module. In the case of relay triggering, the vehicle manufacturer determines which and how many stages can be switched on. In the case of the control unit integrated in the booster heater, a distinction is made between minimum and high functionality. In the case of minimum functionality, the stages are switched individually.

The electronic power module protects the booster heater against excess voltage, short-circuit and inverse polarity. A diagnosis possibility has not be provided for with this control unit. In the case of control stages, up to eight stages are possible. Triggering depends on current balancing and booster heater requirements, i.e. the thermal comfort required. In the case of regulation with high functionality, the electronic power module is triggered infinitely by the LIN or CAN bus on the vehicle side, for example. This means that the current provided by the vehicle wiring system in every situation can always be used optimally for the booster heating. In addition to protection against excess voltage, short-circuit and polarity inversion, the electronic power module with high functionality features excess current protection per stage, protection for the PCB against overheating and voltage monitoring. Regulation with high functionality is diagnosis capable.

Effects of failure

A faulty PTC booster heater can become noticeable as follows:

- Reduced heater power when the engine is cold
- A fault code is stored in the fault memory

The following can be considered as possible causes:

- Electrical triggering or electrical connectors of the PTC booster heater are faulty
- PTC booster heater is faulty (electronic power module, resistors)

Troubleshooting

Test steps towards recognising faults:

- Check fuse
- Read out fault memory
- Read out measured value blocks
- Check electrical triggering (relay)
- Check electrical connections

The vehicle wiring system control unit in many vehicles uses the so-called "load management" feature to regulate the PTC booster heater and switches it off if the vehicle wiring system is overloaded. The load management status can often be recalled using the measured values blocks. If there are complaints about the heating performance, reading out the fault memory and the measured values blocks can provided information about whether or not an excess load on the vehicle wiring system has led to the booster heater being switched off. A faulty booster heater must also be considered as the possible cause of excess load.

9.6 Visco® clutch General points

The Visco® clutch is part of the Visco® fan. If has the task of creating the frictional connection between the drive and the fan wheel depending on temperature, and thus influencing its speed. There is a plastic fan attached to the clutch which generates the air flow as required.
Visco® fans are mainly used in cars with longitudinally-mounted large-capacity engines and in trucks.

Design/Function

The Visco® clutch is usually driven directly by the engine via a shaft (Fig. 1). If no cooling air is required, the Visco® clutch switches off and continues to run at a lower speed. As requirements increase, silicone oil flows from the storage area into the working area. There, the drive torque is transferred to the fan, the continuously variable speed of which is set automatically on the basis of the operating conditions by means of wear-free viscous friction.

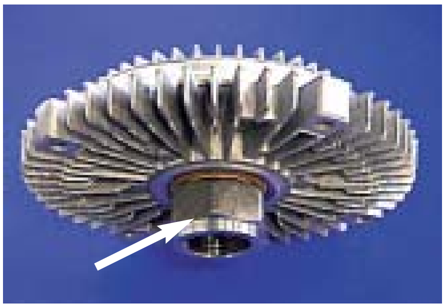


Fig. 1

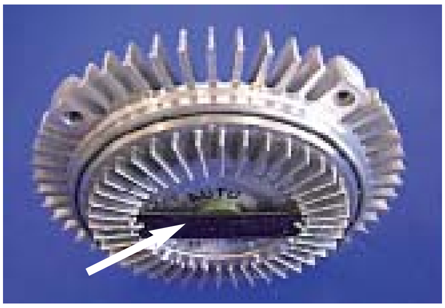
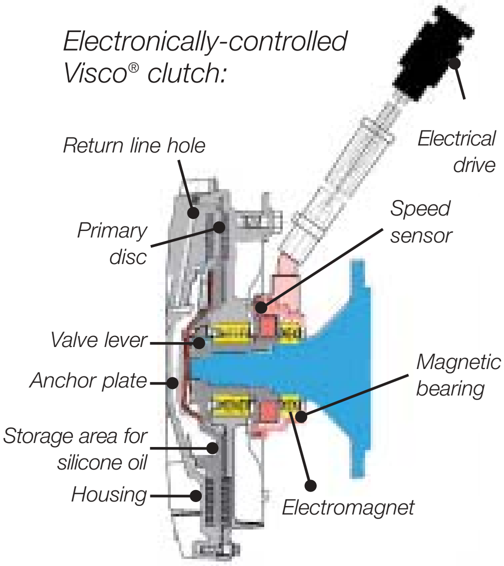


Fig. 2

The switching point is around 80 °C. In the case of conventional Visco® clutches, the air expelled by the fan meets bi-metal (Fig. 2), the thermal deformation of which has the effect of opening and closing a valve via a pin and valve lever. Depending on the valve position and thus the amount of oil in the working area, the transferred torques and fan speeds are set. The amount of oil required is 30 - 50 ml (passenger car). Even with the working area completely full there is a difference between the speed of the drive and that of the fan (slip). The heat produced is dissipated to the surrounding air via the cooling ribs.
In the case of the electrically triggered Visco® clutch, control takes place directly via sensors. A regulator processes the values and a pulsed control current carries these to the integrated electromagnet. The defined guided magnetic field regulates the valve which controls the internal oil flow via an armature. An additional sensor for fan speed completes the regulator circuit.

Effects of failure

Electronically-controlled Visco® clutch:



A faulty Visco® clutch can become noticeable as follows:

- Increased engine temperature or coolant temperature
- Heavy noise development
- Fan wheel continues to run at full speed under all operating conditions

The following can be considered as possible causes:

- Lack of frictional connection through leaking oil
- Loss of oil due to leak
- Soiling of the cooling area or bi-metal
- Internal damage (e.g. control valve)
- Bearing damage
- Damaged fan wheel
- Permanent full frictional connection due to faulty clutch

Troubleshooting

Test steps towards recognising faults:

- Check the level of coolant and the antifreeze content
- Check the Visco® clutch with regard to outer soiling and damage
- Check the bearing for play and noises
- Make sure no oil is leaking
- Check the Visco® clutch by turning it by hand with the engine switched off. With the engine cold, the fan wheel should be easy to turn and with the engine hot it should be hard to turn.
- If possible check the slip of the clutch using speed comparison between the speeds of the fan and the drive shaft. With full frictional connection, the difference may only be max. 5% for directly driven fans. An optical speed measuring device with reflective strips is suitable for this purpose (Fig. 3)
- Check the electrical connection (electronically-triggered Visco® clutch)
- Check air cover/air baffle plates
- Make sure there is enough air flowing through the fan

Fig. 3

9.7 Visco® fans
General

To dissipate heat in the case of commercial-vehicle and high-power passenger-car engines, not only are powerful radiators required, but also fans and fans drives that provide cooling air in a particularly efficient manner. Visco® fans (Fig. 1) consist of a fan wheel and a Visco® clutch. They are used in the case of longitudinally-mounted engines. They are fitted in front of the radiator (direction of travel) and are driven by a V-belt or directly by the engine.

Fig. 1

Effects of failure

The fan wheel (Fig. 2) is usually made of plastic and is screwed to the Visco® clutch. The number and position of the fan blades vary according to design. The housing of the Visco® clutch is made of aluminium and has numerous cooling ribs (Fig. 3). Control of the Visco® fan may be accomplished by a purely temperature-dependent, self-regulating bimetallic clutch. In relation to this, the controlled variable is the ambient temperature of the coolant radiator. The electrically-triggered Visco® clutch is another variant. This is controlled electronically and is operated electromagnetically. Here, the input quantities of different sensors are used for control. Further information can be found in the technical information for Visco® clutches.

Fig. 2

A defective Visco® fan can become noticeable as follows:
- Significant noise development
- Increased engine and coolant temperature

The cause of this may be:
- Damaged fan wheel
- Oil loss/Leaks
- Contamination of the cooling surface or of the bimetal
- Bearing damage

Fig. 3

Troubleshooting

Test steps when troubleshooting:
- Check the coolant level
- Check the fan wheel for damage
- Check for oil leaks
- Check the bearing for play and noises
- Check the fastening of the fan wheel and the Visco® clutch
- Check to make sure that the air-baffle plates/air cover are present and fitted tightly

9.8 Heat exchanger General points

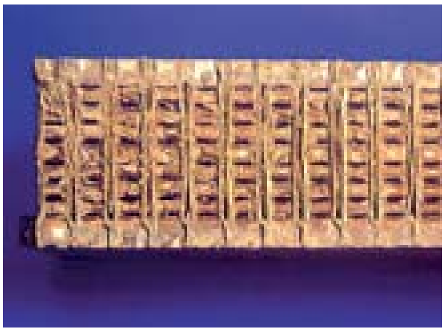
The heat exchanger is installed in the heating box of the vehicle interior and has coolant flowing through it. The interior air is routed through the heat exchanger and thus heated up.

Fig. 1

Structure/function

Like the coolant radiator, the heat exchanger is made up of a mechanically jointed pipe/fin system. The trend is moving to all-aluminium design here, too. Coolant flows through the heat exchanger. The flow quantity is usually controlled by mechanically or electrically controlled valves. The interior air is heated up via the cooling fins (network) of the heat exchanger. The air flow produced by the interior fan or the wind blast is routed through the heat exchanger which has hot coolant flowing through it. This heats up the air which is returned to the inside
of the vehicle.

Effects of failure



Poor performance caused by deposits

A faulty or poorly working heat exchanger can become noticeable as follows:

- Poor heating performance
- Loss of coolant
- Odour build-up (sickly-sweet)
- Fogged windows
- Poor air flow

The following can be considered as possible causes:

- Poor heat exchange caused by external or internal impurities (corrosion, coolant additives, dirt, limescale deposits)
- Loss of coolant through corrosion
- Loss of coolant through leaky connections
- Soiled interior filter
- Impurity/blockage in the ventilation system (leaves)
- Faulty flap control

Troubleshooting

Test steps towards recognising faults:

- Watch out for smells and windows fogging
- Check interior filter
- Check heat exchanger for leaks (hose connections, beading, network)
- Watch out for impurities in/discolouring of the coolant
- Check coolant flow (blockage through foreign matter, limescale deposits, corrosion)
- Measure coolant inlet and outlet temperature
- Watch for blockages/foreign matter in the ventilation system
- Check flap control (recirculated air/fresh air)

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