991231

Thermal Management of Close Coupled Catalysts

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ABSTRACT

The close coupled catalytic converter, together with the manifold and exhaust pipes, form a group of components that emit powerful heat energy. For temperature controle of the neighboring components, limiting the converter surface temperature in the same way as with underfloor systems will not be satisfactory for close-coupled converter systems, as the converter's surface temperature does not represent the only physical measure for assessing the thermal load on other components. Instead, it makes more sense, to control the heat output of the exhaust system and the heat transfer to the other components by choosing materials for the included surfaces which show good proporties to reduce radiative heat transfer.

1. INTRODUCTION

The rising demand for mobility, in the service sector as well as in the private sphere, will of necessity give rise to a growing number of automobiles on the road. Trying to reduce the ever-increasing burden on the environment from pollutant exhaust gases, legislators worldwide are reacting with increasingly stringent emission controls. In mid-1996 the ECE Stage III emission control standards for 1999 have been proposed by the European Community; concurrently, a further reduction for 2005 was proposed as ECE Stage IV. These new standards, in conjunction with a modification of the European exhaust gas test will lead the way to closer approximation with, and an approach comparable to the demands of emission legislation in the United States of America and in particular, California. As in the American FTP (Federal Test Procedure) test, the 40-second idle phase will no longer be applied in the new European test, with emission tests beginning immediately with engine cranking.

In addition to the technical cost intensive external heating methods (electrically heated catalytic converter [1], [2], fuel driven auxiliary burner [3], etc.), the close-coupled catalytic converter layout in conjunction with catalyst-heating functions in the engine management system represents a viable, cost-effective solution [4], [5]. The prerequisite for efficient function of the system is the optimization of the catalytic converter configuration to accommodate these altered conditions. With the example of a close-coupled catalytic conversion system with engine-powered catalyst-heating functions in conjunction with secondary air, the contribution demonstrates and confirms the influence of support material, cell density and mass on emission results, leading through emission and temperature processes during the decisive warm-up phase (the first 150 second of the FTP-test) - using fresh and aged converters, through to an appropriate catalytic converter layout.

The favoured position of the close-coupled catalytic converter for rapid warm-up and high conversion rates can, however, cause problems for thermal management within the engine compartment [6]. The catalytic converter, together with the manifold and exhaust pipes, form a group of components that emit powerful heat energy. These components come into close contact with some heat-sensitive parts, such as the air filter housing, air intake-box, belt-drive cover etc. Compared to systems, where the catalytic converter is located beneath the chassis, when placed in a position close the engine, the converter's temperature reaches a much higher level.

Furthermore, the increasing number of auxiliary and secondary units in the engine compartment of modern vehicles leads to an accumulation of components and at the same time to a reduction in the distance between the separate units. The consequence of this build-up in the engine compartment is that it becomes harder to remove the heat energy released by the exhaust system.

Overcrowding in the engine compartment can also limit the opportunities for insulating the exhaust system. It is therefore preferable to incorporate measures that will protect these parts and which, in the absence of any precious space, will ensure the lowest possible temperature for these parts.

With the catalytic converter beneath the chassis, such considerations played a subordinate role. The main concern there lay in limiting the converter's surface temperature so that materials beneath the vehicle did not catch fire [7] (e.g. burnt grass). This was particularly important for the period after the engine was turned off. The absence of cooling air, together with the thermal heat of the catalytic converter could lead to temperature peaks.

Limiting the converter surface temperature in the same way as with underfloor systems will, however, not be satisfactory for close-coupled converter systems, as the converter's surface temperature does not represent the only physical measure for assessing the thermal load on other components. Instead, it makes more sense, when assessing the thermal load on other components in the engine compartment, to look closely at the temperatures of those parts.

2. THEORY

When assessing the thermal load of other units and components (referred to from now on as 'components'), it is of interest to examine which parameters significantly influence their temperature in the engine compartment.

Figure 1, for example, shows an exhaust system with a catalytic converter, which is positioned in the engine compartment close to the engine. In the immediate area of the exhaust system such components as the belt-drive cover, air filter housing and air intake can be identified.

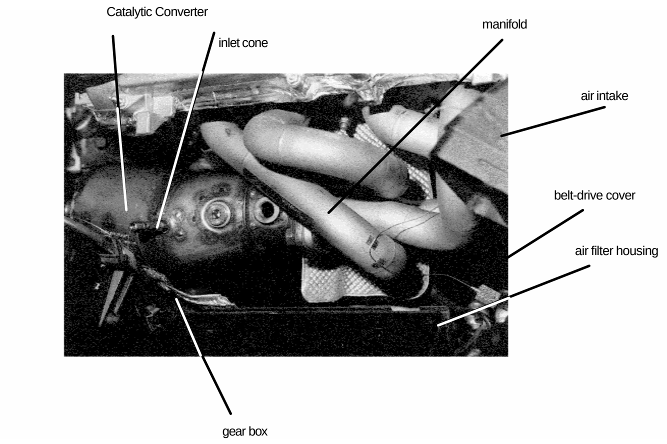

Fig. 1: *A photograph of an exhaust system with a close-coupled catalytic converter, plus a number of other components in close proximity*

To clarify the relationship between the temperature of a component near the exhaust system and the values which affect these, the set-up is simplified in Figure 2.

The heat transfer from the exhaust system to the component takes place in the form of conduction, convection and radiation.

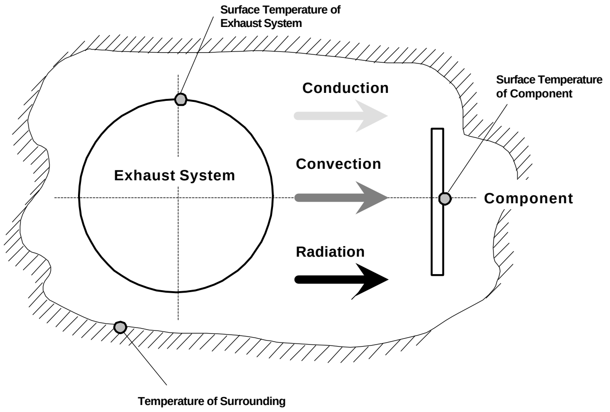

Fig. 2: *Schematic diagram of the heat transfer of exhaust systems to an adjacent component*

Conduction:

If the influences of convection within the air surrounding the exhaust system are ignored (cf. Fig. 2), then the emitted heat energy given off by the exhaust system (in the following regarded as a cylindrical converter) into the air by means of conduction is as follows [8]:

$$\dot{Q}_{cond} = \frac{2 \cdot p \cdot L \cdot l}{\ln(1 + \frac{x}{r_{Cat}})} \cdot (T_{Cat} - T_U) \qquad (1)$$

$\dot{Q}_{cond}$ = conduction heat transfer rate

λ = heat conductivity of air

L = converter length

x = distance from the surface of the converter

r_{Cat} = catalyst radius

T_{Cat} = surface temperature of the exhaust system

T_u = temperature of surrounding

When calculating the heat energy transferred to the component, the *distance* from the connverter and its *surface temperature* is significant. However, the low heat conductivity of air is a limiting factor.

Furthermore, pure heat conduction exept convection can only be assumed under certain conditions, e.g. when the component is positioned near or beneath the hot catalytic converter and there is no external air flow (stationary vehicle). In all other arrangements and vehicle conditions, conduction plays a more subordinate role than convection and radiation, as will be described in the following chapters

Convection:

Convective heating of the component is to be expected in all those cases, where the component is either so near to the catalytic converter, that it enters into the boundary layer that surrounds it, or when the physical position of the component permits a convective flow (free or forced) from the catalytic converter to the component. The transferred heat flow can then be described as follows [9]:

a) For the heat transfer from the catalytic converter to the surrounding air:

$$\dot{Q}_{Cat,Air} = HTC_{Cat,Air} \cdot A_{Cat} \cdot (T_{Cat} - T_{Air}) \quad (2)$$

$$with \quad HCT_{Cat,Air} = \frac{Nu \cdot l}{L_{Cat}} \quad (3)$$

$$and \quad Nu(free\ convection) = f(Gr, \Pr)$$

$$or \quad Nu(forced\ convection) = f(\mathrm{Re}_{forced}, \Pr)$$

$\dot{Q}_{Cat,Air}$ = convective heat transfer rate to the surrounding
HCT $_{Cat/Air}$ = convective heat transfer coefficient
A $_{Cat}$ = converter outer surface area
T $_{Cat}$ = surface temperature of the exhaust system
T $_{Air}$ = temperature of surrounding air
Nu = Nusselt number
Gr = Grashof number
Re = Reynolds number
Pr = Prandtl number
L $_{Cat}$ = length of the catalytic converter subjected to flow (e.g. π x D/2)

b) For the heat transfer from the air to the component:

$$\dot{Q}_{Air,Comp} = HTC_{Air,Comp} \cdot A_{Comp} \cdot (T_{Air} - T_{Comp}) \quad (4)$$

$$with \quad HCT_{Air,Comp} = \frac{Nu \cdot l}{L_{Comp}} \quad (5)$$

$$and \quad Nu(forced\ convection) = f(\mathrm{Re}_{forced}, \Pr)$$

$\dot{Q}_{Air,Comp}$ = convective heat transfer rate to the component
HCT $_{Air, Comp}$ = convective heat transfer coefficient
L $_{Comp}$ = length of component subject to flow (e.g. length)

In practice, free convection around the catalytic converter's components is overridden more or less strongly by forced flows because of the air ducting inside the engine compartment. By suitably designed measures (air ducting), it is possible to control both catalytic converter cooling and the heating up of adjacent components.

In both processes, the *surface temperature* of the catalytic converter is an important influential parameter for determining the Nusselt number with free convection. With preset air flows, it is the *speed of the flow* that plays the most important part.

Radiation:

The catalytic converter, its adjacent components and the surrounding area can be regarded as an enclosed cavity, in which the catalytic converter (= net radiation source) and component (net radiation recipient) can be regarded as non-selective radiators and the surrounding area as a full radiator with the ambient temperature. Q*i* is the net heat energy radiated from a surface i (e.g. from the converter) [10].

$$Q_i = \frac{s \cdot T_i^4 - J_i}{\dfrac{1 - e_i}{A_i \cdot e_i}} \quad (6)$$

$$Q_i = \sum_{j=1}^{n} \frac{J_i - J_j}{\dfrac{1}{A_i \cdot F_{ij}}} \quad (7)$$

$\dot{Q}_i$ = net radiative heat transfer rate from a surface i
σ = Stefan-Boltzmann-number
T*i* = temperature of surface i
J*i* = radiosity of surface i
ε *i* = emissivity of surface i
A*i* = surface area of surface i
n = number of surfaces enclosed in the cavity
F*ij* = view factor, fraction of radiation which leaves surface i and is intercepted by surface j

The radiosity J comprises the emitted and reflected radiation from each body combined. The influence of spatial orientation with one another (including distance) and the geometric dimensions of the radiation partners are accounted for in the view factors.

These equations can be applied to all parts which border the cavity. With their assistance, the individual temperatures can be determined. As well as the positioning of the radiation partners in relation to one another *(distance)*, with radiation it is mainly the *surface temperatures* and the radiation emissivities of the surfaces involved that are significant. To clarify this relationship, a simple calculation was carried out. For a catalytic converter, whose center is maintained at a constant temperature, the heat emitted into the surroundings convectively or by radiation was calculated.

With regard to the convective heat loss, the external heat transfer coefficient determines the emitted heat volumes, while the radiative heat loss is mainly influenced by the converter surface's emissivity. A converter's surface temperature and also the total heat volume emitted by the catalytic converter is dependent on these values.

As Fig. 3 shows, the total of the catalytic converter's convective and radiative heat output increases strongly with a rising emissivity, while its surface temperature falls corresponding with the growing energy loss.

From this it follows that through selective reduction in the emissivity of the catalytic converter's surface, the heat input into the engine compartment can be significantly lowered. The rising converter surface temperature indicates the higher thermal energy level of the catalytic converter.

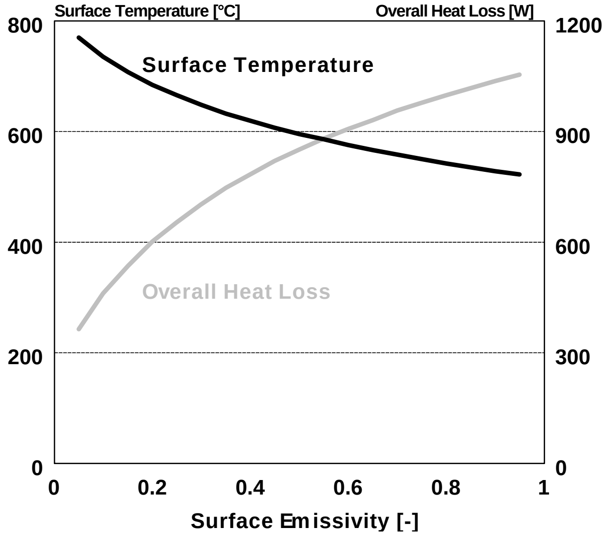

Fig. 3: *The influence of the converter's surface emissivity on the heat emitted from the catalytic converter into the surrounding air, plus the converter surface temperature at a constant converter bed temperature of 900°C*

A final summarisation shows the influences which principally determine the heat energy transferred to a component and consequently its thermal load.

- **I. Catalytic converter – component distance (conduction)**
- **II. Speed of free and/or forced flow around the catalytic converter and component (convection)**
- **III. Radiation emissivities from catalytic converter and component (radiation)**
- **IV. Surface temperature of the catalytic converter**

The consequence of the combined effects of influences I-III is that the characteristic surface temperatures for the whole system is set by the component and catalytic converter. The surface temperature of the catalytic converter is indeed a determining factor for a component's thermal load, however, it is also determined by the factors listed above.

Furthermore, the surface temperature of the catalytic converter is also influenced by the quality of the insulation.

3. DEFINITION OF THE EXHAUST SYSTEM

When limiting the heat energy transferred from the exhaust system to the surrounding components, it is often forgotten that heat emanates not only from the catalytic converter itself, but also from all the other elements in the exhaust system, such as the pipes and cones (cf. Fig. 4).

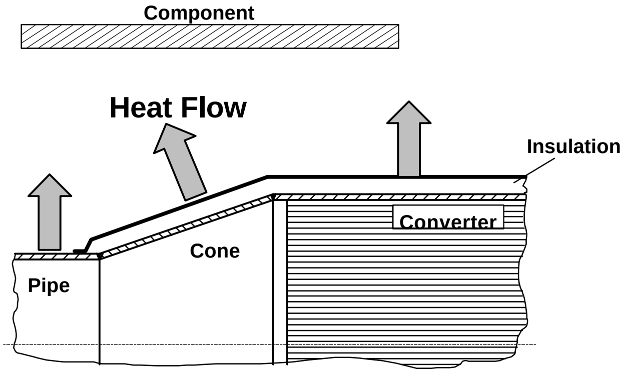

Fig. 4: *Heat emitting elements of the exhaust system: catalytic converter, cones, pipes in close proximity to a component*

It is therefore important that all measures intended to reduce heat output and/or component thermal load, should be applied to all elements of the exhaust system, i.e. not just to the converter, but also to the pipes and cones. Measures applied to only individual elements, e.g. to the converter, are ineffective, as a component's thermal load from the non-insulated elements, e.g. the cone, is unchanged. This is clarified in Fig. 5.

Shown here are the surface temperatures on an air-gap insulated catalytic converter, its non-insulated entry and exit cones and the three surface temperatures of the adjacent component (sheet metal, distance from converter ca. 15 mm). The temperature sensors on the exhaust system were directly opposite the sensors on the sheet metal.

The differences between the temperatures recorded on the component show that exhaust system insulation fitted only partially around the catalyst is of little value, because the thermal load on an adjacent component is high and unchanged on account of the non-insulated sections.

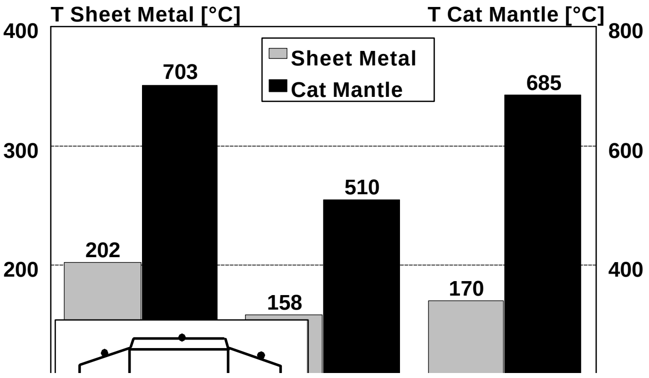

Fig. 5: Surface temperatures measured on an air-gap insulated catalytic converter, its non-insulated cones and also on the corresponding sections of the adjacent component (sheet metal)

4. MEASUREMENT SET-UP / IMPLEMENTATION

4.1 TEST BENCH SET-UP

All tests were carried out on the test bench represented in Figure 6. On this test bench, air is drawn in by a blower through an air flow sensor. From the blower it passes through a cut-off valve into an air heater where it can be heated to a maximum of 750°C. Where temperatures in excess of 750°C are required, 4 additional electrically heated converters (each 2 kW) can also be put into operation, so that temperatures up to 1000°C are possible. The blower mass flow can be adjusted by its revolutions with the aid of a generalized phase control.

The outer heat transfer was held constant by constant room temperature.

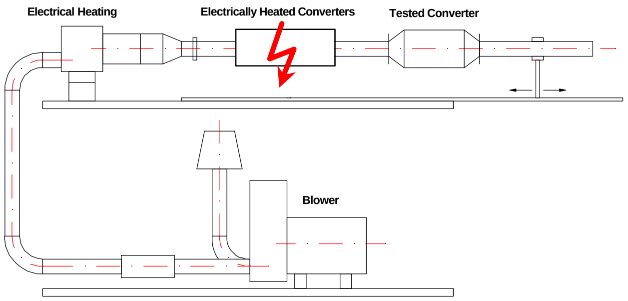

Fig. 6: *Schematic plan of the test bed for measuring the temperatures on the catalytic converter and component*

4.2. TESTED CATALYTIC CONVERTERS AND COMPONENTS

- **Test converter:**
  Metall converter: Ø 110x110 mm 500 cpsi TS
  Foil thickness: 0.04 mm
  Structure uncoated
  Converter mantle: 1.5 mm

For the converter mantle, different mantle materials / mantle coatings have been used (see Table 1). In order to be able to quantify in advance the surface emissivities of the converter surfaces under investigation, these were determined by measurement. For the zirconium dioxide coated converter and the converter with an aged ferrite mantle (see Table 1) approximately similar values of 0.7 and 0.65 respectively were obtained. For the aged austenitic mantle and the aluminium surface, noticeably lower emissivities of 0.4 and 0.15 respectively were recorded.

Converter mantle surface	**Emissivity at 700°C**
Aluminium coated *	0.15
Aged austenite **	0.4
ZrO_2-coated ***	0.65
Aged ferrite **	0.7

* - foil coated
** - Ageing: 100h, 800°C, Air
*** - spray coated

Table 1: *Radiation emissivities from various catalytic converter surfaces*

- **Component:**
  Sheet metall, 100 x 50 x 1,5 mm
  uncoated (glossy), varnished (black)

Again, before the tests, the surface emissivity of both, the glossy and the black metal sheet was determined. The result was an emissivity of 0,1 for the glossy and 0,9 for the black variant.

- **Arrangement:**
  For testing of the influences on the sheet metal temperature representing a component, it was placed beside the converter as described in Fig. 7, to prevent convection influencing the results. The position of the the sheet metal to the test bench was adjustable, in order that the distance from the converter could be varied.

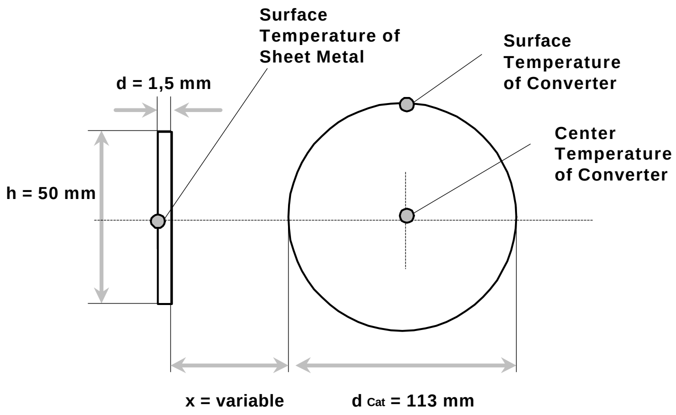

Abb. 7: *Arrangement of converter and sheet metal (neighboring component) on the test bench*

4.3 TEST PROCEDURE

The test converter was installed in the flow apparatus described above and subjected to a mass flow of steady state air at 65 kg/h. The temperature was adjusted for converter center temperature of 900°C.

The catalyst system was provided with thermocouples for measurement of the temperature 25 mm upstream and downstream from the converter, in the center of the converter, against the outer skin of the converter on its top and against the back of the metall sheet (cf. Figure 7). The outer converter temperature was measured at the top of the converter system in the axial centre.
The system was brought to the required temperature and the thermal point of equilibrium was awaited. Subsequently, the temperatures were recorded.

4.4 TESTED VARIANTS FOR THE SYSTEM CONVERTER AND COMPONENT

The following variations were planned for the system converter / component to test the influence of these parameters on heat creation within the engine compartment and on the component’s surface temperature:

- Variation in the insulation quality of the converter
  - ⇒ Air Gap
  - ⇒ Air Gap + heatshield
  - ⇒ Several ceramic fiber insulations

- Variation in the emissivity of the converter mantle
  - ⇒ Converter mantle covered with glossy aluminium foil
  - ⇒ Converter mantle consisting of aged 309 (austenite)
  - ⇒ Converter mantle consisting of aged 441 (ferrite)
  - ⇒ Converter mantle coated with ZrO_2

- Variation in the distance between converter and component
  - ⇒ 5 to 35 mm

- Variation in the emissivity of the component
  - ⇒ uncoated (glossy)
  - ⇒ varnished (black)

5. TEST RESULTS

5.1 INFLUENCING THE CATALYTIC CONVERTER’s SURFACE TEMPERATURE

As shown in the introductory example (Section 2, Fig. 3), the temperature of the exhaust surface is set among other things according to the parameters of surface emissivity and the insulating quality of the system. In the tests carried out here, the influence of both parameters was investigated.

Insulation:
Fig. 8 represent the results of converter mantle temperature measurements on three of the various insulating methods: air gap insulation, air gap insulation with additional heatshield and air gap filled with ceramic fibres. It is easy to identify the advantage of air gap insulation with heatshield/ceramic fibre, as the surface temperature compared to air gap insulation on its own drops by between 50 and 70°C (345°C and 352°C respectively as against 415°C). In contrast to air gap insulation, the two other systems are capable of reducing the radiation exchange between the converter mantle and the double mantle.

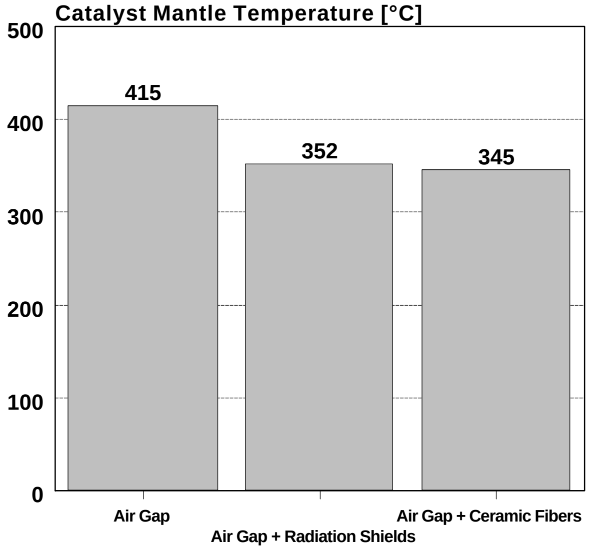

Fig. 8: *The influence of three different insulation variants for metal catalytic converters on converter mantle temperatures at a bed temperature of 900°C*

In the context of these investigations, in addition to the types of insulation described in Fig. 8, a series of others were tested, which consisted of ceramic fibers of various densities (see Fig. 9).

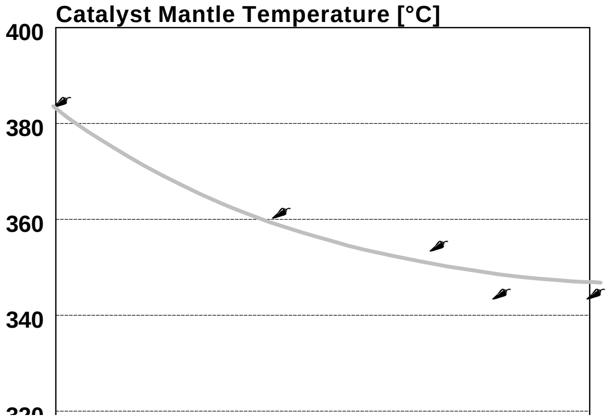

Fig. 9: *Influence of the densities of various types of ceramic fiber insulation applied to metal catalytic converters on the converter surface temperature at a catalyst bed temperature of 900°C*

It can be clearly identified that the effectiveness of the insulation can be improved by raising the fiber density to values of about 330 kg/m³. No further reductions in the converter surface temperature were noted at higher densities, according to [11].

The conclusion of all measurements carried out was that the surface temperature could not be reduced with justifiable expense further than the levels shown in Figs. 8 and 9.

The reason for this is the increasing solid matter conduction is opposite to all measures aimed at reducing radiation exchange. Conceivable solutions to this problem are highly porous materials with low solid matter conduction. Such materials do exist but are not yet commercially viable.

In the subsequent tests the influence of radiation was investigated, because as known, the influence of radiation's share on heat transfer increases dramatically with growing temperature. An example for this is given by the following illustration (Fig.10), which demonstrates the influence of the converter's inner mantle temperature on the heat transfer coefficient within the air gap of an air gap insulated metallic substrate [6].

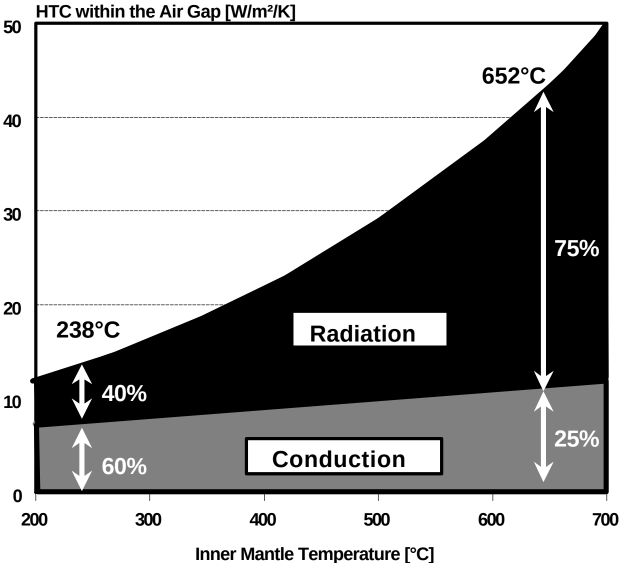

Fig. 10: *Influence of the converter's inner mantle temperature on the heat transfer coefficient within the air gap of an air gap insulated metallic substrate*

Surface emissivity:

Measurements were taken on non-insulated catalytic converters, their surface qualities and thus emissivity being subjected to variation.

The emissivities of the converters, listed in Table 1, Section 4.2, suggest that an aluminium coated converter surface would be a very efficient method to keep the converter's surface emissivity low. However, the physical and chemical proporties of aluminium (melting point, oxidation) will not allow its use in such applications. The results are shown in Fig. 11. As was to be expected, at a constant central temperature of 900°C, with rising emissivities, falling catalytic converter surface temperatures were observed.

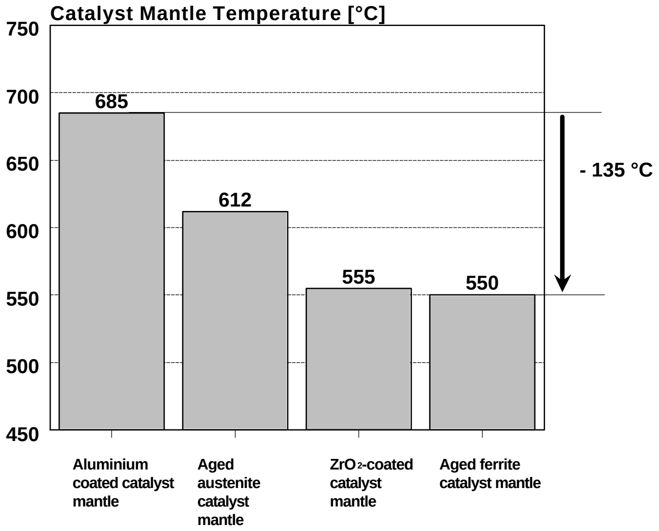

Fig. 11: *Influence of the converter surface on catalytic converter surface temperatures at a constant converter bed temperature of 900°C*

In order to compare the influence of the catalytic converter's surface emissivity with the influence of various types of insulation on the heat output of catalytic converters, a computational example was carried out.

Two variants were compared to each other. Both were based on a metal catalytic converter with air gap insulation, and the bed temperature was kept constant. The heat output into the surrounding area was in both cases via free convection and radiation, the heat transfer in the air gap by means of convection and radiation.

These were the variations:

Variant 1:

constant: catalytic converter insulation
variable: reducing emissivity of the converter

mantle from 0.7 to 0.4

Variant 2:

constant:	converter mantle emissivity = 0.5
variation:	improving catalytic converter insulation in such a way that the mantle temperature falls from 415°C to 350°C

With a variation in the emissivity of the converter mantle and unchanged catalytic converter insulation, the range between 0.7 and 0.4 was selected, as this can be simply represented in practice.

Similarly, the corresponding parameters in the variation of insulation quality were set in such a way that real measured surface temperatures were obtained (Fig. 8). The reduction in heat output was then determined. The results of this assessment is recorded in Table 2.

Constant	Variation	Reduction in Heat Loss
Insulation quality	Reduction in emissivity of the mantle from 0.7 to 0.4	12%
Emissivity of the converter mantle	Improvement in insulation, so that T mantle falls from 415°C to 350°C	25%

Table 2: *Reduction in the heat output of a catalytic converter by reducing the converter surface temperature and/or by improving converter insulation*

These figures show that by simply replacing the converter mantle material with an alternative, commercially available material, the heat entry into the engine compartment can, without any additional cost, be reduced by half the amount that can be achieved by the use of insulation.

<u>Conclusion:</u>

Despite a rising surface temperature, by reducing the radiation emissivity of the converter mantle, the heat output of the catalytic converter falls.

Reducing heat loss by using a mantle material with a lower emissivity supplements the insulation on the exhaust system.

5.2 THE INFLUENCE OF THE MANTLE MATERIAL ON EMISSIVITY

In order to obtain an impression of the oxidation process of various converter mantle materials as well as the effect on emissivity, samples of austenitic CrNi steel (309) as well as ferrite Cr steel (441) were aged in air in a laboratory oven for a period of 100 hours temperature of 800°C. The result is shown in Fig. 12.

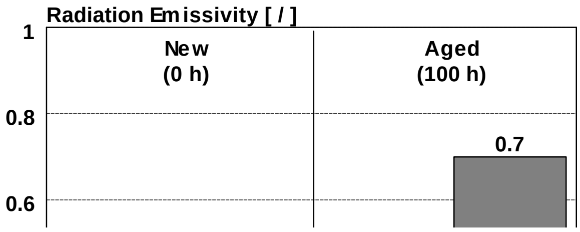

Fig. 12: *Influence of converter mantle material and the ageing period on surface emissivity (exposure in air to a temperature of 800°C for 100 h)*

In a cool, non-oxidised condition, it is possible to measure with both ferrite and austenite very low emissivities of around 0.15. In the course of time, a rapid rise to values of about 0.7 was recorded for the Cr steel, while the CrNi steel remained at more moderate values of about 0.4.

The cause is the clearly superior resistance to oxidation of austenite and the different behaviors of both materials in growth in the oxide layer over longer periods.

<u>Conclusion:</u>

Over a longer period of ageing, austenitic mantel material clearly displays a lower emissivity than a ferrite mantle

5.3 THE INFLUENCE OF THE DISTANCE BETWEEN CATALYTIC CONVERTER AND COMPONENT ON THE COMPONENT'S TEMPERATURE

In the previous measurements, exhaust system heat loss and measures to reduce it were at the forefront of our attention. In this section, the role of the component, represented by a piece of sheet metal beside the catalytic converter, is examined.

The distance between the converter and component formally comes within the view factors sphere of influence. These factors indicate what proportion of the radiation emanating from the converter affects the sheet metal and vice versa [10].

Fig. 13 illustrates this connection. In the chosen example, both components represent in geometric terms an infinitely long cylinder and a sheet of infinite length, arranged parallel to one another at a defined distance.

Fig. 13: *Influence of the distance between converter and component on view factors (infinitely long sheet and cylinder arranged in parallel)*

As can be seen, the proportion of the radiation emitted from the exhaust system to the component drops only slowly as the distance between the two increases. As the transferred heat volume depends directly on the visual factor [10], no significant reduction in the component's thermal load can be expected by increasing the distance.

In order to check this, measurements regarding the influence of the distance were taken. The converter/component arrangement (infinitely long cylinder and parallel sheet) on which this calculation was based is relatively similar to the Fig. 7 experiment.
As the results in Fig. 14 show, with distances from 10 and 15 mm respectively, the temperature of the component changes only very slowly as the distance increases. The calculated results from Fig. 13 mainly apply here.

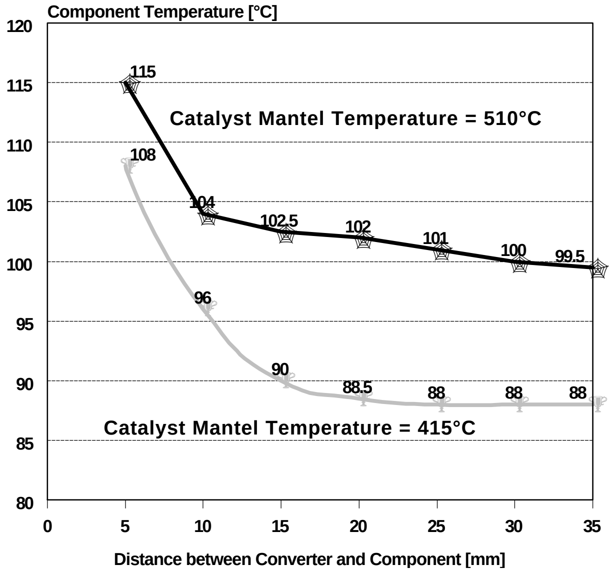

Fig. 14: *Influence of the distance between the catalytic converter and neighboring component (blank metal strip) on the temperature of the component at a constant converter bed temperature of 900°C*

The rapid increase in the sheet metal temperature for distances smaller than 10 mm can be explained by the effects of conduction/convection.

Conclusion:
In the positioning of converter and component here, the distance from each other is of practically no importance, as long as a minimum distance is maintained

5.4 THE INFLUENCE OF THE CATALYTIC CONVERTER'S SURFACE EMISSIVITY ON THE ADJACENT COMPONENT'S TEMPERATURE

This section also examines the influence of the radiation emissivity of a component positioned beside the exhaust system.

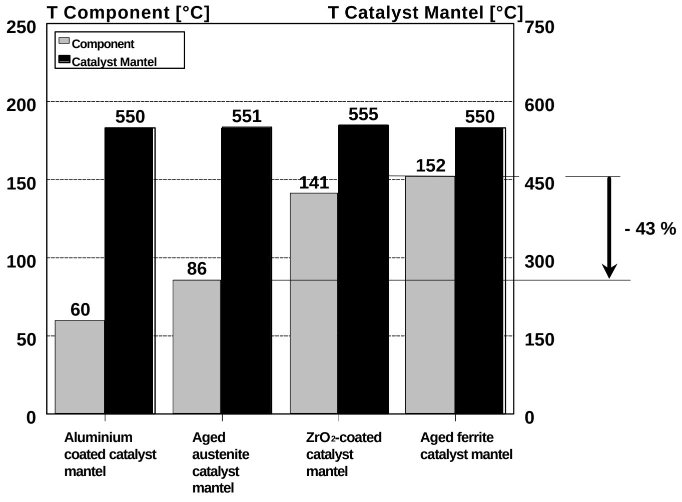

Fig. 15: *Influence of the surface qualities of the catalytic converter on the temperature of a component (blank metal strip) at a constant converter surface temperature of 555°C and a constant distance of 25 mm*

Fig. 15 records the results of temperature measurements on the blank, metallic surface of sheet metal, which was positioned in accordance with Fig. 7 opposite various high emission converter surfaces. The distance from the converter was in each case set at 25 mm.

In order to take account exclusively of the influence of the converter emissivity, the measurements on the converter were taken at a constant temperature of 555°C. The bar graph shows a clear drop in the sheet metal temperature when using the converter mantle materials in Section 4.2 (Table 1, Fig. 11): aged ferrite, ZrO_2-coated, aged austenite, aluminium-coated ferrite. By using a material with an emissivity of 0.4 instead of 0.7, for example, the component temperature can be reduced by 43% (Fig. 15).

In a second experiment, the influence of the converter surface temperature was taken into consideration. The measurements were taken at a constant converter central temperature, so that the various converter surface temperatures accorded with the various surface emissivities of the already known test catalytic converters.

The various converter surface temperatures and emissivities gave rise to temperatures on the adjacent sheet metal, as shown in Fig 16.

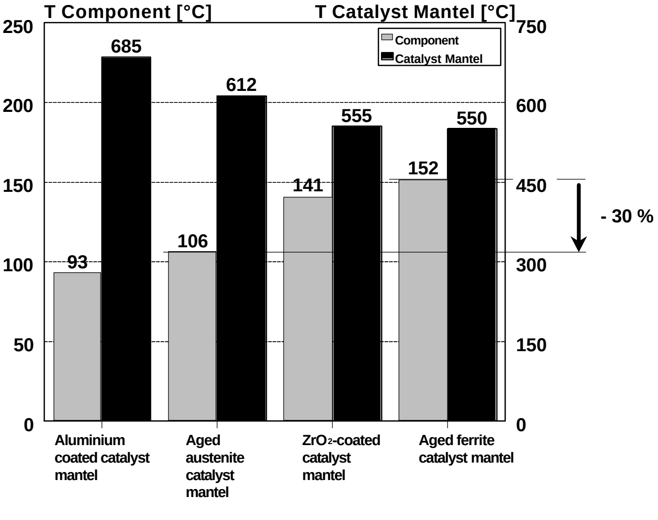

Fig. 16: *Influence of the surface qualities of the catalytic converter on the temperature of a component (blank, metal strip) at a constant converter bed temperature of 900°C and a constant distance of 25 mm*

Although the converter surface temperature rises with the decreasing surface emissivity of the catalytic converter (cf. Fig. 11), the temperature of the sheet metal decreases very clearly. The comparison between the aged austenitic and aged ferrite mantle material shows a 30% lower component temperature with austenite.

It can therefore be concluded that the influence of the converter surface emissivity on the temperature of a component is significantly greater than the influence of the temperature of the converter surface. It then follows that, when assessing a component's thermal load, the surface temperature of the catalytic converter is not the appropriate measure. This fact must be taken into consideration in any specifications.

<u>Conclusion:</u>

The influence of the catalytic converter's surface emissivity on the temperature of the component is greater than the influence of the temperature of the cat surface.

Þ ***Thus, when assessing a component's thermal load, the surface temperature of the catalytic converter is not the only appropriate measure***

5.5 THE INFLUENCE OF THE ADJACENT COMPONENT'S SURFACE EMISSIVITY ON ITS TEMPERATURE

- ***Examples and temperature limits for components:***

The following is a list of those components, which may be positioned close to the converter and which therefore play a role in these considerations. Also given is the maximum tolerable surface temperature of the component.

Component	**Material**	**Max. tolerable temperature**
Air filter housing	Plastic	140°C
Air intake	Plastic	140°C
Side member	Plastic	110°C
Wiring harness	Plastic	120°C
Engine mounting	Rubber	100°C

Table 3: *List of some components and their maximum temperatures*

The table shows that the majority of components in the vicinity of the converter can only withstand temperatures of little more than 100°C. In addition, the materials involved are plastic or rubber, which normally have relatively high emission coefficient values. There is great potential here for reducing the component's surface temperature.

- ***Test results:***

In order to be able to assess the influence of the component's surface on its temperature, the measurements discussed in Section 5.3 were modified. The same test catalytic converters were used, however, the sheet metal with a glossy metallic surface was replaced by one with a black varnished surface (see Section 4.2 and 4.4).

The black surface was turned towards the catalytic converter and the sheet metal was positioned, as in the previous experiments, at 25 mm from the catalytic converter.
As shown in Fig. 17, as a result of the different emissivity of the now black metal strip in case of constant converter mantle temperature of 550°C, its temperature rose between 70 and 89%, depending on the surface of the catalytic converter used.
On the basis of these results, it can be established that the reduction of the component's emissivity itself is certainly one of the most effective ways of reducing a component's thermal load. As Table 3 shows, the majority of the components in question are made from various plastics or rubber, i.e. materials which usually have a relatively high emissivity and also have relatively low maximum application temperatures.

Fig. 17: *The influence of the emissivity of catalytic converters and adjacent component (sheet metal) on the temperature of the component at a constant converter surface temperature of 550°C and a constant distance of 25 mm*

Looking at the more realistic case of testing at a constant converter bed temperature of 900°C exhibits the entire potential for reducing the thermal load of a component (Fig. 18).

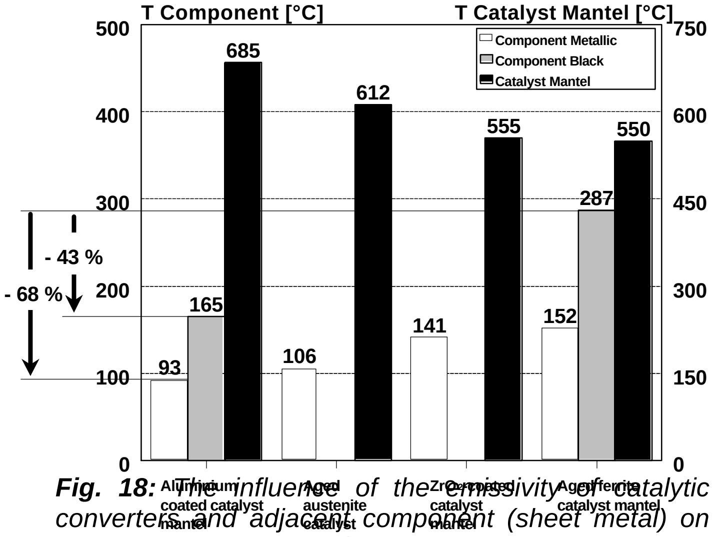

Fig. 18: *The influence of the emissivity of catalytic converters and adjacent component (sheet metal) on the temperature of the component at a constant converter bed temperature of 900°C and a constant distance of 25 mm*

In an unfavorable case of high emissivities of converter and component a dramatically high component temperature of 287°C is achieved, which can be reduced by 43% only by reducing the converter's surface emissivity. A further reduction of almost 70% (overall) can be achieved by an additional reduction of the component's surface missivity.
There is therefore a starting point here for very effectively controlling component temperature at little expense, e.g. by using bonded and/or vapour deposited aluminium surfaces.

<u>Conclusion:</u>
Simple and effective control of the component temperature can be achieved by reducing the emissivity of the component.

6. SUMMARY

- ***All measures intended to reduce heat output, should be applied to all elements of the exhaust system (manifold, cones, catalytic converter), as otherwise the component's thermal load is unchanged***

- ***Despite a rising surface temperature, by reducing the radiation emissivity of the converter***

mantle, the heat output of the catalytic converter falls

- ***Reducing heat loss by using a mantle material with a lower emissivity supplements the insulation on the exhaust system***

- ***Austenitic mantle material clearly displays a lower emissivity than a ferrite mantle***

- ***In the positioning of converter and component here, the distance from each other is of practically no importance, as long as a minimum distance is maintained***

- ***The influence of the catalytic converter's surface emissivity on the temperature of the component is greater than the influence of the temperature of the converter surface.***
  - Þ ***Thus, when assessing a component's thermal load, the surface temperature of the catalytic converter is not the only appropriate measure***

- ***Simple and effective control of the component temperature can be achieved by reducing the emissivity of the component***

7. REFERENCES:

[1] Hanel, F.-J.; Otto, E.; Brück, R.: " Electrically Heated Catalytic Converter (EHC) in the BMW ALPINA B12 5.7 Switch-Tronic", SAE-Paper 960349, 1996

[2] Hanel, F.-J.; Otto, E.; Brück, R.; Nagel, T.; Bergau, N.: " Practical Experience with the EHC System in the BMW ALPINA B12", SAE-Paper 970263, 1997

[3] Öser, P.; Müller, E.; Härtel, G. R.; Schürfeld, A. O.: "Novel Emission Technologies with Emphasis on Catalyst Cold Start Improvements Status Report on VW-Pierburg Burner/ Catalyst Systems", SAE-Paper 940474, 1994

[4] Pfalzgraf, B.; Rieger, M.; Ottowitz, G.: "Close-coupled Catalytic Converters for Compliance with LEV/ULEV and EG III-Legislation – Influence of Support Material, Cell Density and Mass on Emission Results", SAE-Paper 960261, 1996

[5] Otto, E.; Albrecht, F.; Liebl, J.: "The Development of BMW Catalyst Concepts for LEV/ULEV and EU III/IV Legislations 6 Cylinder Engine with Close Coupled Main Catalyst", SAE-Paper 980418, 1998

[6] Breuer, J.; Brück, R.; Diewald, R.; Hirth, P.: "Temperature Examinations on a Metal Catalyst System", SAE-Paper 971028, 1997

[7] Hartsock, D. L.; Stiles, E. D.; Bable, W. C.; Kranig, J.V.:"Analytical and Experimental Evaluation of a Thermally Insulated Automotive Exhaust System", SAE-Paper 940312, 1994

[8] Wagner, W.: "Wärmeübertragung", Vogel-Verlag Würzburg, 1993

[9] VDI-Wärmealtlas, VDI-Verlag Düsseldorf

[10] Baehr, H. D.; Stephan, K.: "Wärme- und Stoffübertragung", Springer-Verlag Berlin, 1994

[11] Ganz, R.: "Untersuchungen zur Anwendungsgrenztemperatur von keramischen Hochtemperaturfasern des Systems Al2O3-SiO2", Dissertation an der Fakultät Bergbau und Hüttenwesen, RWRH Aachen