

„Der Hybridkatalysator, ein neues Katalysatorkonzept zur verbesserten Ausnutzung der Abgasenergie und Steigerung der Effektivität von Dieselmotorsystemen“

“The Hybrid Catalyst, a New Catalyst Concept to Improve Utilization of Exhaust Gas Energy and Increase the Efficiency of Diesel Catalyst Systems”

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Abstrakt:

Zur Einhaltung der zukünftigen weltweiten Emissionsgesetzgebung für Dieselfahrzeuge ist eine Erhöhung der Katalysatoreffektivität für alle Schadstoffkomponenten erforderlich. Neben verbesserten Motoren und Motormanagementsystemen muß der Oxidationskatalysator an die spezifischen Randbedingungen eines modernen Dieselmotors angepaßt werden. Die katalytische Effektivität von Oxydationskatalysatoren ist hauptsächlich von der Katalysatortemperatur und damit von der Abgastemperatur abhängig. Betrachtet man moderne hocheffektive Dieselmotoren liegt die Abgastemperatur vor allem bei Stadtfahrten innerhalb des Bereichs der Light-Off Temperatur. Zur Steigerung der Effektivität ist deshalb neben einer motornahen Lage eine verbesserte Ausnutzung der Abgasenergie erforderlich. Durch die Kombination einer schnellen Light-Off und einer Wärmespeicherfunktion in einem kompakten Bauteil, sorgt der Hybrid Katalysator für ein optimiertes Wärmemanagement.

Abstract:

In order to comply with future worldwide legislation on emission limits for diesel vehicles the efficiency of the catalyst must be improved for all emission components. Apart from improving engine and engine management systems, the oxidation catalyst must also be adapted to the specific requirements of modern diesel engines. The efficiency of oxidation catalysts depends mainly on the temperature of the catalyst and hence the temperature of the exhaust gases. In the case of highly efficient modern diesel engines, the temperature of the exhaust gases is within the range of the light-off temperature, especially when driving in urban areas. An improvement in efficiency therefore requires better utilization of the exhaust gas energy as well as locating the catalyst closely to the engine. By combining fast light-off with a heat storage function in one compact component, the hybrid catalyst provides optimum thermal management.

1. Introduction

In 2002, over one third of all newly registered vehicles in Germany had a diesel engine. Traditionally, this share is even higher in countries such as France and Austria. The sharp increase in the number of diesel vehicles is due their fuel economy – particular in the case of engines with direct injection systems – and comparatively low diesel prices, as well as the “fun factor”. The performance, impressive torque characteristics and comfort of today’s diesel vehicles make it difficult to distinguish them from comparable vehicles with a petrol engine. Above all it is because of the lower specific fuel consumption and consequently the reduced emission of the alleged greenhouse gas CO₂ – a political issue that is subject to heated debate – that the automobile industry has become interested in the diesel engine.

An examination of worldwide legislation on emission control leads to the conclusion that the diesel engine has been considered separately because of its lower fuel consumption as well as its lower raw emissions compared to spark ignition engines. This is particularly true for particle emissions (pm), which are considerably higher than those emitted by spark ignition engines.

Hydrocarbon (HC) and carbon monoxide (CO) emissions from diesel engines can be oxidized by an oxidation catalyst similar to that used in petrol engines. However, the reduction of nitrogen oxides (NO_x) under lean (oxygen-rich) conditions is more problematic. Here the three-way catalyst used in petrol engines fails. Technologies for the reduction of nitrogen oxides, such as Selective Catalytic Reduction (SCR) with the addition of a reducing agent [1, 2, 3], or NO_x absorbers used in DI petrol engines [4, 5] could, in principle, also be applied here. Their utilization has, however, not been required yet, since to this day engine out emissions have always been reduced by further improvements in engine technology.

Because of the introduction of considerably stricter worldwide emission regulations in the next few years, all car manufacturers are increasingly paying attention to emission treatments for diesel vehicles.

An important factor that complicates the treatment of diesel engine emissions are the generally very low temperatures. These are caused by the usually large volume of excess air, and also by the fact that the exhaust gas turbo charger used in most modern diesel engines extracts additional energy from the exhaust gas. As a result the period until the necessary light off temperature has been reached in the catalyst is very long, e. g. for the European Driving Cycle. In addition to this there is the fact that during deceleration, particularly when driving in urban areas, the exhaust temperature will at times fall below the ignition temperature and hence greatly reduce the efficiency of the catalyst. In order to comply with future emission limits it will become necessary to improve existing oxidation catalysts and, if necessary, fit a particle filter or implement NO_x exhaust gas after-treatment. Due to the large number of required components the development must focus on compact, cost-effective and highly efficient catalysts that are specially designed to match the requirements of diesel engines.

2. Hybrid Catalysts

Because of the low exhaust temperatures mentioned above the objective of the oxidation catalyst development must be fast heating and slow cooling of the catalyst. These contradictory requirements can be fulfilled by a catalyst substrate with two different, separate substrate structures. At the front there is a short disc of thin foil and hence low thermal capacity to ensure fast light-off. At the back the matrix has a thick foil (high thermal capacity) in order to be able to store as much heat as possible and hence prevent the monolith from cooling down too quickly.

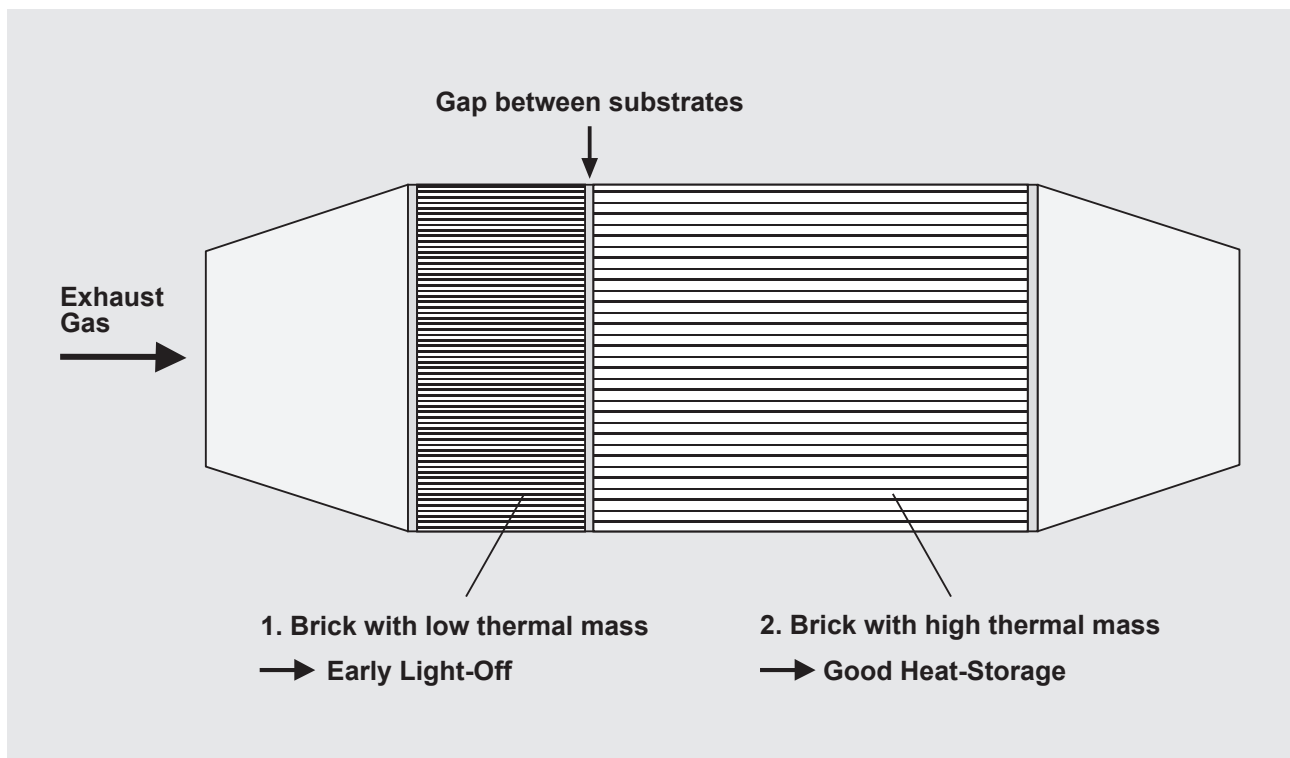


Figure 1: Construction principle of the hybrid catalyst

The distance between the two substrate halves can be adjusted from 0 mm to a wider gap (e. g. 30 mm). The size of the gap above all affects flow distribution and pressure loss. In case of substrates directly placed against of each other (zero gap) the angle of rotation, that is, the alignment of the cell channels in relation to each other, becomes a factor that has to be taken into consideration.

Both pressure loss and flow distribution were measured on flow test bench with concentric air flow (figures 2a, 2b, 3).

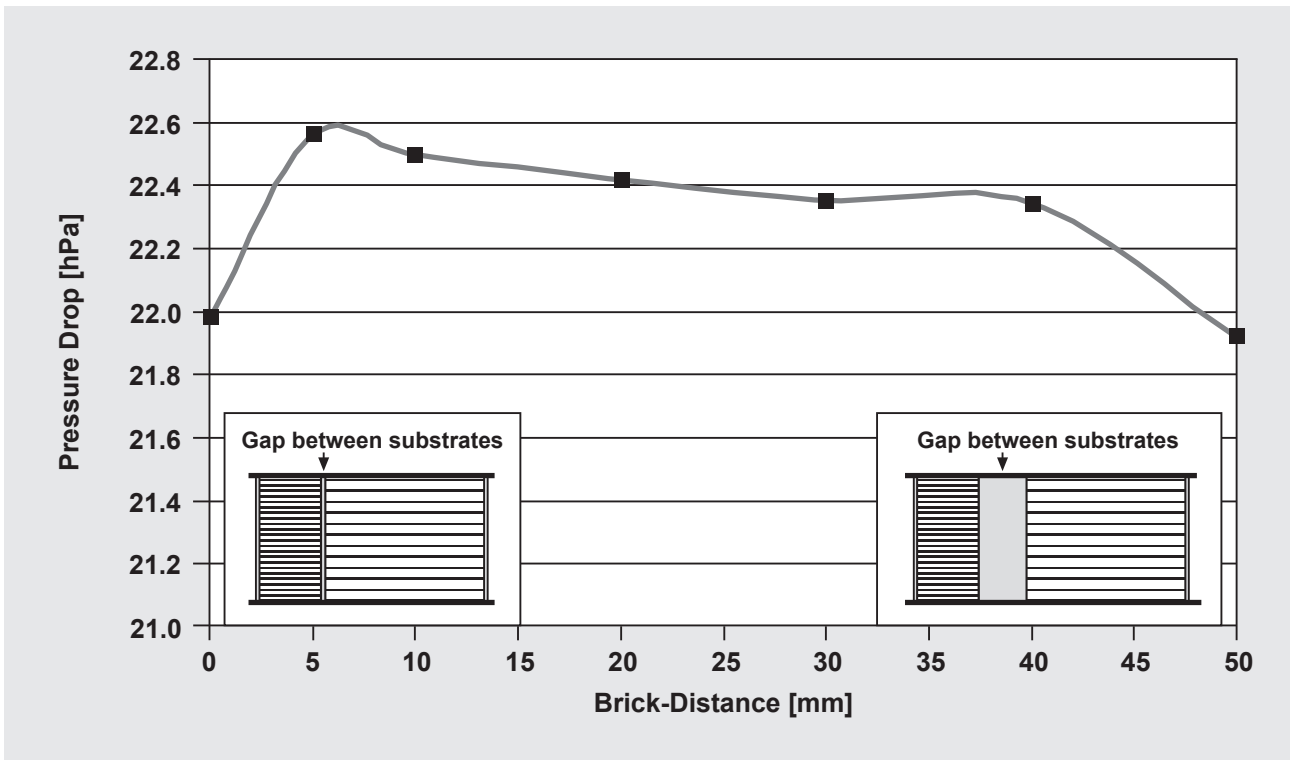


Figure 2a: Pressure loss as a function of the gap between the two substrate halves

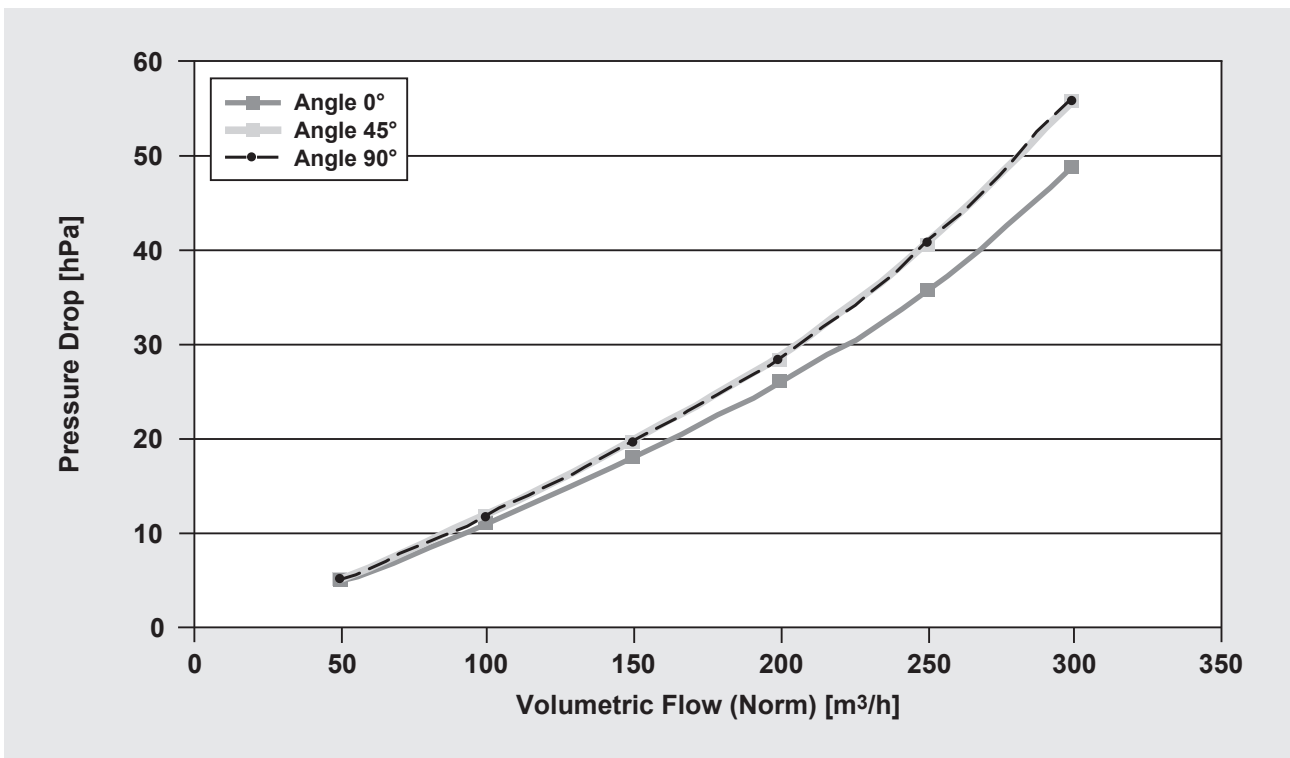


Figure 2b: Pressure loss as a function of the angle of rotation between the two substrate halves to each other



Figure 3: Uniformity index as a function of the gap between the two substrate halves (massflow 444 kg/h; room temperature; catalyst \varnothing 93 x 78 mm/600 cpsi/40 μ m uncoated)

It becomes clear that both pressure loss and flow distribution depend only on the size of the gap. An increase in the gap improves flow distribution but also increases pressure loss.

In the case of the hybrid catalyst used in these tests the two substrate parts were fitted directly on top of each other without a gap. Figure 4 shows a sectional view of the hybrid catalyst \varnothing 98.4 x 95 mm. The total length is divided into an inlet zone of 30 mm with a foil thickness of 0.03 mm and an outlet zone of 65 mm with a foil thickness of 0.08 mm.

In order to minimize the heat loss during heating up the catalyst substrate was additionally fitted with an air-gap insulation between the matrix and the mantle in the gas inlet zone. Figure 5 shows the radial heating behavior of the substrate with and without air-gap insulation. Specially in the structure close to the catalyst mantle higher temperature can be seen especially of the air gap insulation.



Figure 4: Sectional view of the hybrid catalyst with air-gap insulation on the gas inlet zone

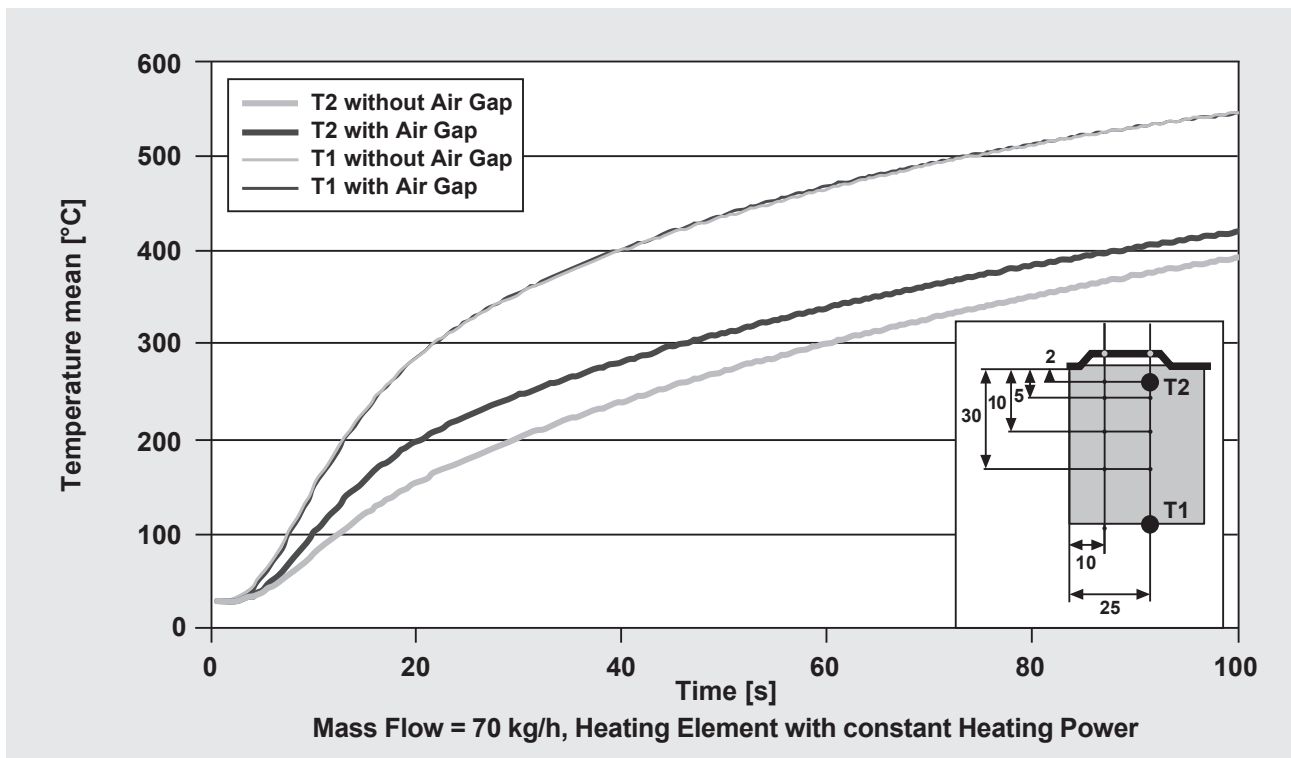


Figure 5: Radial heating behavior with and without air-gap insulation in the inlet zone

3. Emission Testing

Emission testing was carried out on a Honda passenger car on a roller test bench in accordance with the new European Driving Cycle. All catalysts had been aged to 62,000 miles on an engine test bench according to the Honda DE Catalyst Acceleration Aging Mode (HDCAA). The aging cycle includes temperature aging and poisoning.

3.1 Test Set-Up

The following catalyst systems were measured. The dimensions of the hybrid catalysts were \varnothing 98.4 x 95 mm; 400 cpsi. The foil thickness was 0.03 mm on the inlet zone and 0,08 mm on the outlet side. The dimensions of the underfloor catalyst were \varnothing 113x 130 mm, 400 cpsi, 2 pieces inline. Each catalyst was coated with a loading of 4 g/l; Pt only.

- Reference system close-coupled (Metal, 0.6 l, 400 cpsi/0.03 mm + underfloor Metal 1.8 l, 400 cpsi/0.03 mm)
- Hybrid catalyst close-coupled + reference underfloor catalyst
- Hybrid catalyst close-coupled + air-gap insulated underfloor catalyst

The gas temperatures in front of the close-coupled catalyst and in front of the underfloor catalyst are shown in figure 6.

Figure 7 shows the accumulated second-by-second CO tailpipe emissions in order to examine the behavior of the different catalyst systems.

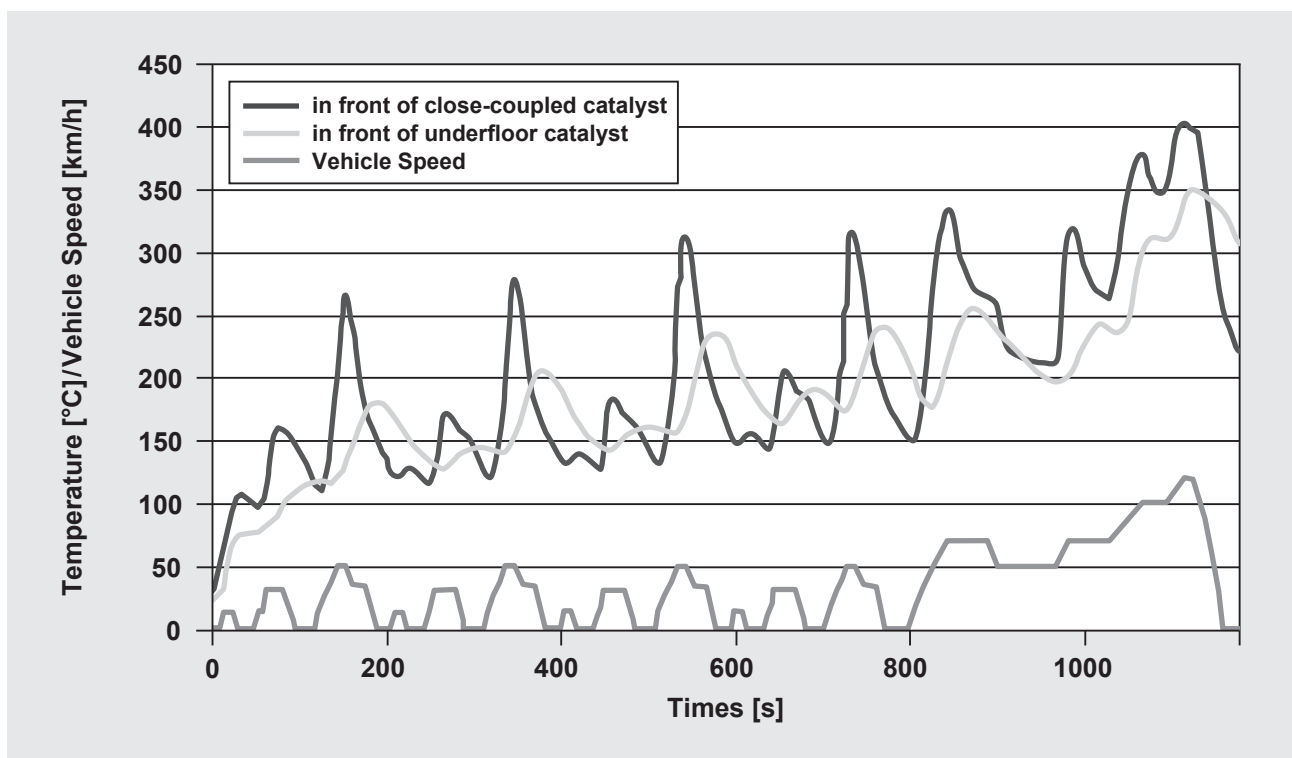


Figure 6: Gas temperature in front of the close-coupled and in front of the underfloor catalyst during the new European Driving Cycle

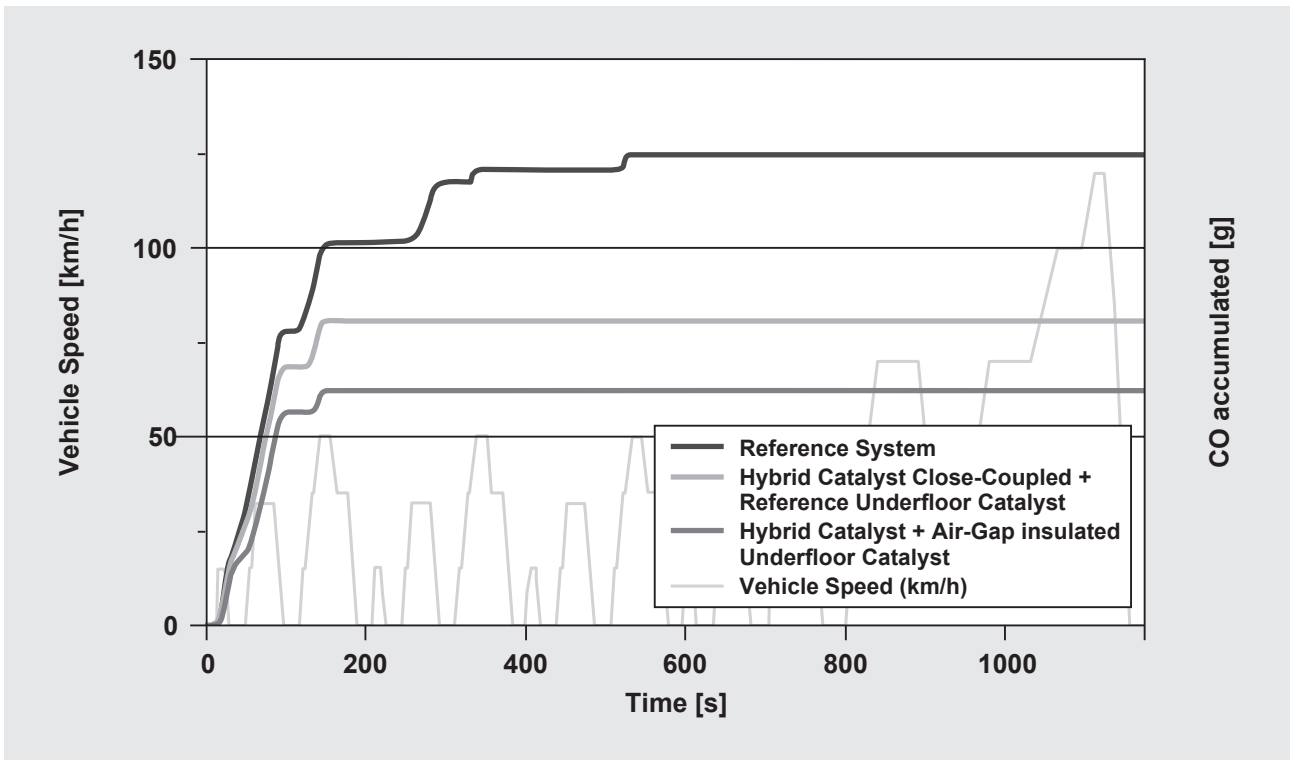


Figure 7: Accumulated second-by-second CO tailpipe emissions of the different tested catalyst systems

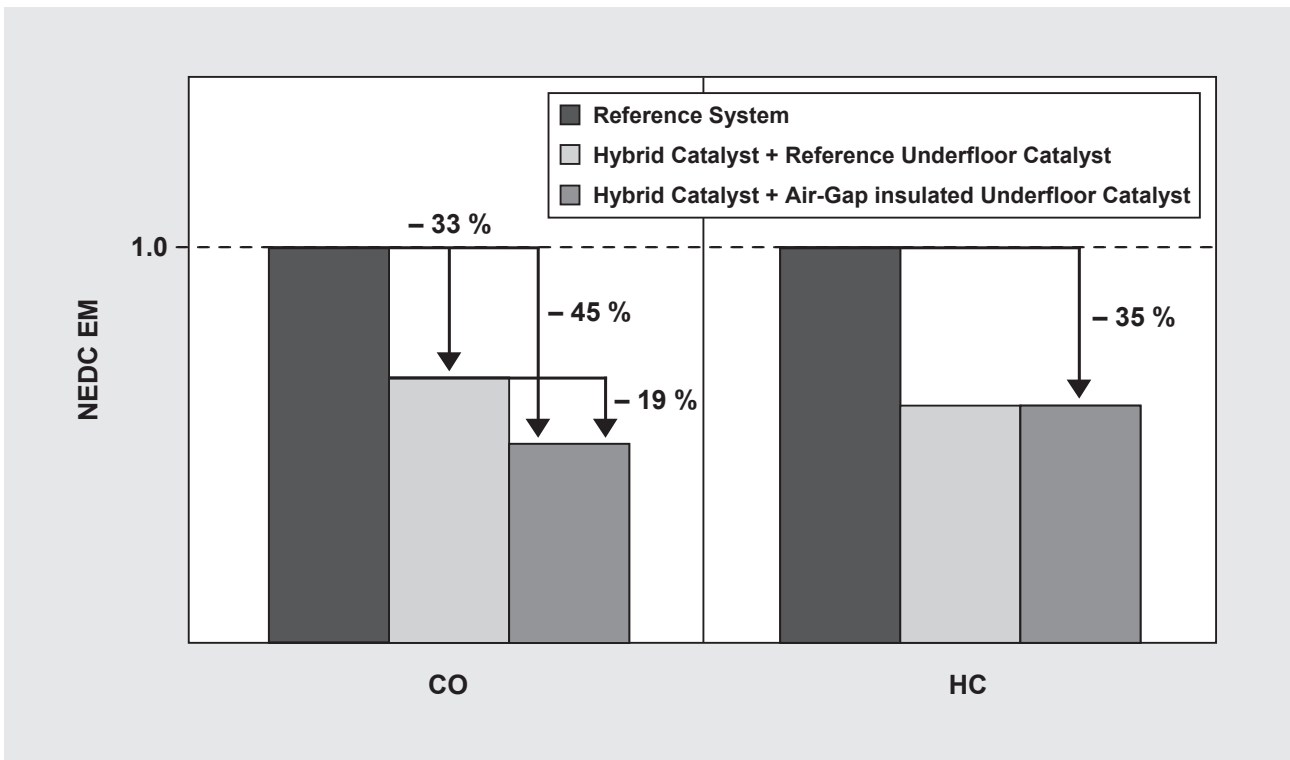


Figure 8: CO and HC emission results of the reference system in comparison with a hybrid catalyst with and without air-gap insulated underfloor catalyst in the new European Driving Cycle

When comparing the reference system with the hybrid catalysts during the first 600 seconds it becomes clear that cold start behavior and efficiency after idling times have been improved above all. After 600 seconds the exhaust temperature is always above the light-off temperature so that the hybrid catalyst has no additional benefits. The air-gap insulated underfloor catalyst showed an additional improvement of 19 %.

Figure 8 shows the HC and CO results from the individual test systems. No difference may be found with regard to particle and NO_x emission.

In comparison with the reference system, the hybrid system shows an advantage of 33 % for CO and 35 % for HC. The air-gap insulation additionally increases efficiency with regard to CO by 19 %. HC emissions were not further improved by the insulation.

4. Durability Testing

In contrast to petrol engines, the maximum temperature load of diesel engines is considerably smaller. The fact that almost all diesel engines in passenger cars are fitted with a turbocharger also results in an additional attenuation of the thermal shock load (figure 9).

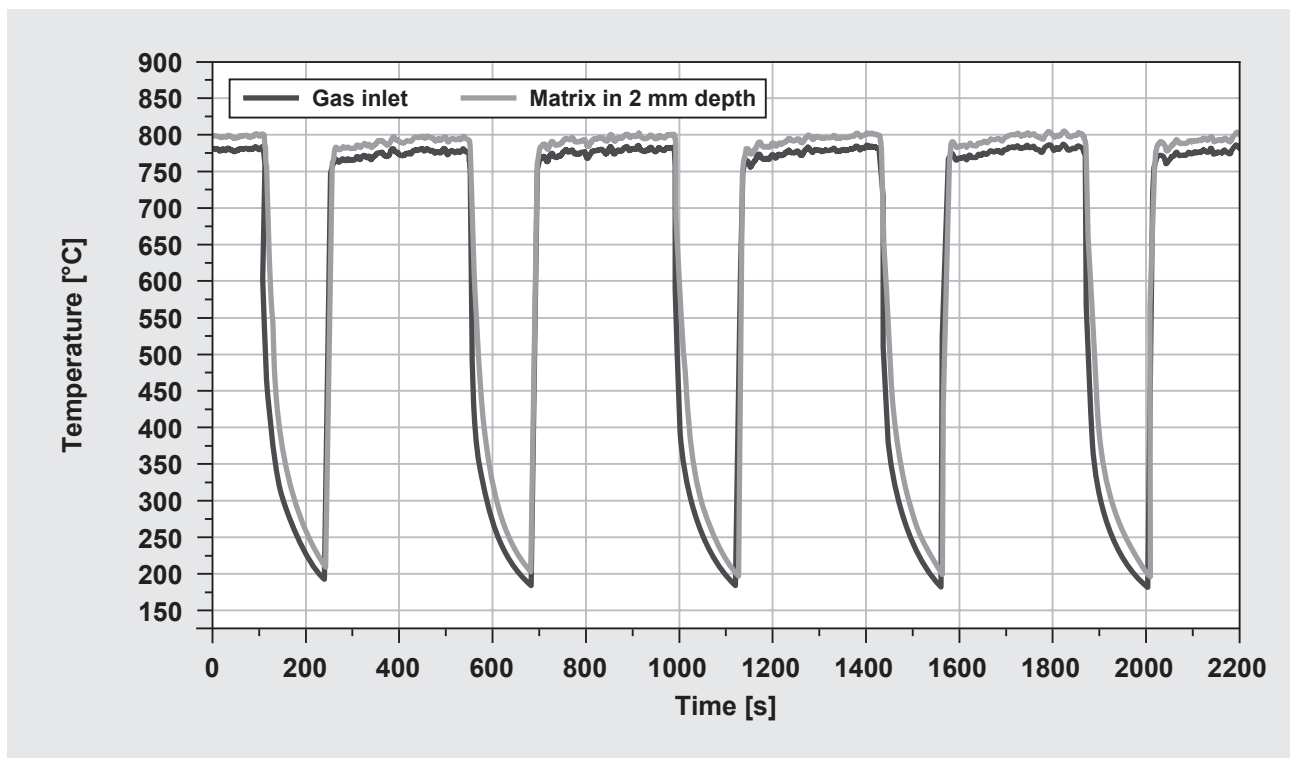


Figure 9: Diesel engine, specific thermal test loads

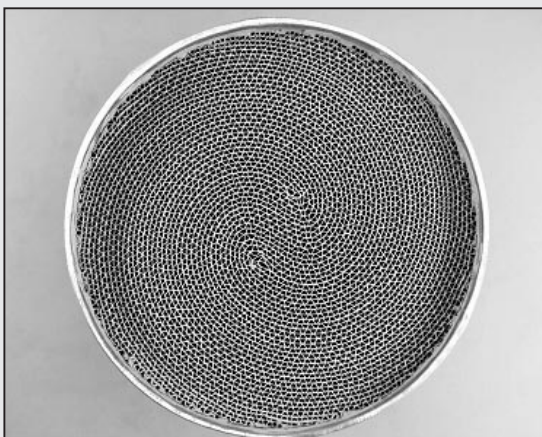
The air-gap insulated hybrid catalyst was tested in an Inner Thermal Cycling Test (ITC) and a Superimposed Test (SIT) with additional superimposed vibrations. For the SIT the catalyst substrate was clamped onto a 45° test rig (figure 10) and subjected to frequency excitation at an acceleration of 30 g peak with a frequency of 100-300 Hz.

Apart from the usual analysis of the catalyst and the mantle/matrix connection, the area where the two matrixes join each other was also examined more closely.

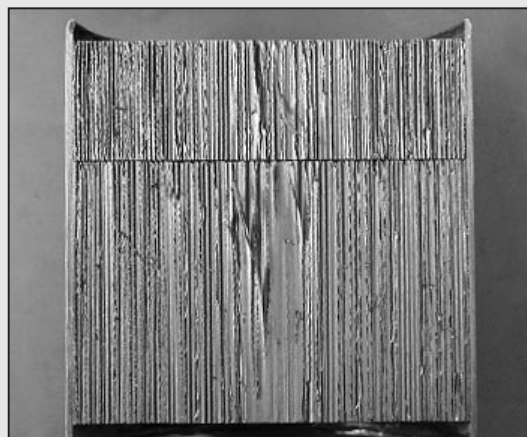


Figure 10: Hybrid catalyst on the 45° test rig

After the test no damage of the supports was found. The size of the zero gap between the two matrix halves corresponded to the gap after the manufacturing process (figures 11a, b). Further tests on the engine test bench also produced positive results.



a



b

Figure 11a: Gas inlet zone of the hybrid catalyst after SIT
b: Longitudinal section of the hybrid catalyst after SIT

5. Conclusion

The hybrid catalyst provides an optimum solution for the oxidation of carbon monoxide and hydrocarbons. The staggered thermal masses facilitate an optimum thermal management of the exhaust temperatures so that the catalyst heats up more quickly or is kept at operating temperature for longer periods.

Tests for long-term durability carried out on the component test bench and on the engine verified the strength of the design.

The hybrid catalyst can be employed to decrease the volume of the underfloor catalyst in order to save costs or to improve the overall efficiency to comply with future exhaust gas limits.

6. Reference

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