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Comparative investigations of different fuel-borne catalysts

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Content

1 Objectives

The objective of this investigation was the test and characterization of a ceriumbased fuel-borne catalysts with respect to it´s influence on the exhaust emission and it´s applicability for the regeneration of a particulate trap. Thereby different additive concentrations were examined. All investigations were carried out according to the defined loading and regeneration procedure as aggreed. For all tests a SiC-particulate trap was used.

2 Plan of investigation

2.1 Test schedule

A test procedure has been set up which consists of two steps. The first one was the loading of the particulate trap and the second one was the regeneration of the filter.

Loading cycle

During the whole loading cycle the engine speed and engine load have been kept constant while the exhaust gas was about 250 °C in front of the particulate trap.

Regeneration cycle

For this cycle the engine speed has been kept constant again whereas the engine load has been raised step by step. The duration of each step was 15 min. The temperature of the exhaust gas in front of the trap increased simultaneously by about 25 °C.

The investigation of each trap consisted of 7 steps as shown in Table 2.1.

Table 2.1: Steps of trap investigation (overview)

no.	step	comment	speed	torque	duration
			rpm	Nm	
1	1. weigh				
2	**loading procedure**				
	engine warm up				
	trap loading		3000	30	7h
3	trap cooling				> 3h
4	2. weigh				
5	**regeneration procedure**				
	engine warm up				
	trap regeneration		3000	30 to 245	165 min
6	trap cooling				> 3h
7	3. weigh				

After measuring the weight of the trap this trap was mounted in the diesel engine exhaust system.

Both the loading and regeneration procedures started with the same engine warm up as specified below:

1500 rpm / 25 Nm until $T_{Water,\ cooler\ outlet}$ > 50 deg. C

1700 rpm / 40 Nm until $T_{Water,\ cooler\ outlet}$ > 70 deg. C

1700 rpm / 95 Nm until $T_{Water,\ cooler\ outlet}$ > 80 deg. C

The raw emission of particulate matter (without additive) in the loading point was about 2.65 g/h. Table 2.2 shows the composition of particulate matter for the selected loading point.

Table 2.2: Raw emission of particulate in loading point

	loading point	
speed	3000	rpm
load	30	Nm
particulate matter (PM)	**2.651**	g/h
soluble organic fraction (SOF)	**1.435**	g/h
	54.0%	
soluble inorganic fraction (SIOF)	**0.265**	g/h
	10.0%	
insoluble fraction, soot (ISF)	**0.954**	g/h
	36.0%	

The loading procedure took 7h and the TPM-load was accounted for 15-17g. After cooling down the trap was weighed again.

The regeneration procedure started with the same engine warm up as the loading procedure. The regeneration procedure consisted of 12 steps. Each step lasted 15 min.

Table 2.3 shows the selected operating points which were used during regeneration.

Table 2.3: Operating points for trap regeneration

Step Number	trap inlet temperature [Deg. C]	engine speed [rpm]	Md [Nm]	duration [min]
Step 1	225	3000	30	15
Step 2	250	3000	41	15
Step 3	275	3000	54	15
Step 4	300	3000	67	15
Step 5	325	3000	84	15
Step 6	350	3000	102	15
Step 7	375	3000	127	15
Step 8	400	3000	146	15
Step 9	425	3000	171	15
Step 10	450	3000	201	15
Step 11	475	3000	219	15
Step 12	500	3000	245	15

The table 2.4 shows measured raw emission of particulate matter (without FBC) in the specified operating points.

Table 2.4: raw emission of particulate matter (without additive) in the operating points of the trap regeneration

Step Number	PM [g/h]	ISF [g/h]	SIOF [g/h]	SOF [g/h]
Step 1	2.651	0.954	0.265	1.435
Step 2	1.394	0.446	0.446	0.502
Step 3	2.380	1.523	0.238	0.619
Step 4	2.497	1.398	0.549	0.550
Step 5	2.549	1.733	0.280	0.536
Step 6	2.575	1.416	0.489	0.670
Step 7	2.657	1.860	0.452	0.345
Step 8	2.632	2.053	0.289	0.290
Step 9	2.895	2.142	0.376	0.377
Step 10	3.261	2.511	0.261	0.489
Step 11	4.239	3.391	0.339	0.509
Step 12	5.718	4.632	0.572	0.514

2.2 Test bench

load generated by:	direct-current machine (DC-machine)
maximum rated power output [kW]:	134
torque [Nm]:	350 / 135
speed [rpm]:	3500 / 9000
test bench automation:	CATS NT by Siemens
fuel consumption measuring instrument:	AVL 733 S
exhaust gas emission measuring instrument:	CO, THC, CO_2, O_2: Advance Optima (Fa. ABB)
	NOx: CLD 700 (Fa. Eco physics)
air mass sensor:	Sensyflow
smoke number measurement:	AVL 415S
soot measuring instrument:	NOVA Microtunnel

2.3 Engine

engine:	DW12TED4/L4 FAT
model:	turbocharged diesel with intercooler air/air
number of cylinder:	4
displacement:	2179cm³
rated power output:	97.5kW
rated engine speed:	4000rpm
maximum torque:	318Nm
maximum speed:	4500rpm
minimum speed:	750rpm

2.4 Test specimen

Particulate trap:

SIC from Ibiden

Type of trap:	SIC (200 cpsi)
size:	5,66”x6”
trap volume:	2,5 litre
trap surface:	approx. 2,5 m^2

Fuel quality:

Standard diesel, Sulfur Content: S= 19 ppm

Fuel borne catalyst:

Table 2.5 shows the investigated fuel borne catalysts.

Table 2.5: fuel borne catalysts for investigation

fuel borne catalyst (FBC)	Concentration [ppm]
Envirox	3
	5
	10
Eolys	10
	25
CDT Pt/Ce	10

3 Test configuration

The test engine has been integrated on the test bench as can be seen in Figure 1. All required media like fuel, cooling water and fresh air were connected with the engine. Due to the objectives of the investigations some special test facilities were integrated in addition to the regular sensors of the test bench.

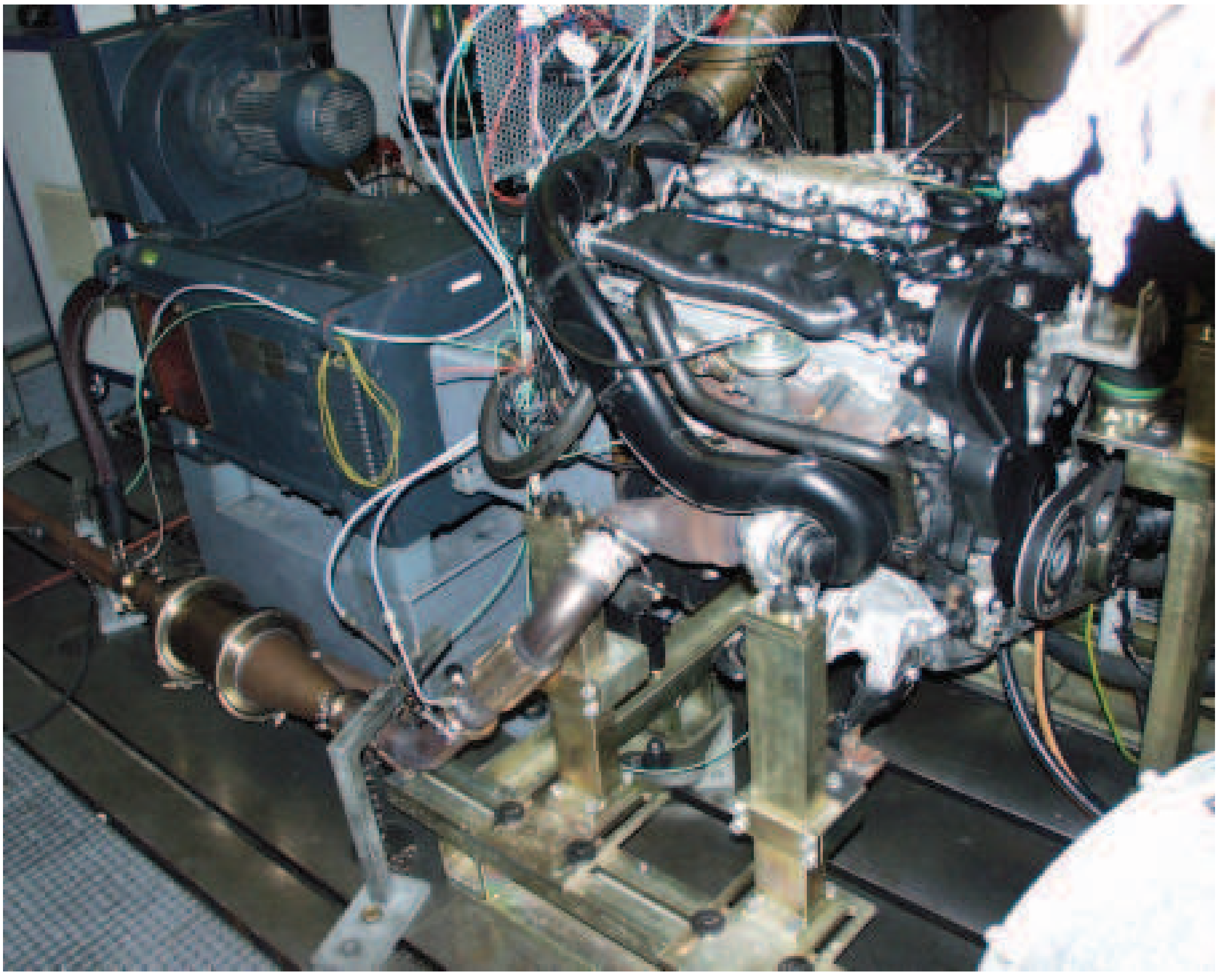

Figure 1: Test engine DW12TED4/L4 and particulate trap at the test bench

Table 3.1 shows all measurement values with the realised measuring interval. For example during the regeneration procedure all values were measured every 5 minutes. The marked values of the rightmost column were measured with an 1 second intervals.

Table 3.1: All measured values including the intervals of measurement

Measurement value		Time between measurement			
Description	Dimension	Loading		Regeneration	
		15 min	10s	5 min	1 s
Date	tt.mm.jj	✓	✓	✓	✓
Time	h:m:s/ms	✓	✓	✓	✓
Speed	rpm	✓	✓	✓	✓
Torque	Nm	✓	✓	✓	✓
Throttle angle	%	✓		✓	
Exhaust temperature before charger	deg. C	✓	✓	✓	✓
Exhaust temperature before trap	deg. C	✓	✓	✓	✓
Exhaust temperature after trap	deg. C	✓	✓	✓	✓
Trap differential pressure	mbar	✓	✓	✓	✓
Exhaust backpressure	mbar	✓	✓	✓	✓
Intake air mass flow rate	kg/h	✓	✓	✓	✓
CO emission	ppm	✓	✓	✓	✓
CO_2 emission	Vol%	✓	✓	✓	✓
THC emission	mgC/m^3	✓	✓	✓	✓
NOx emission	ppm	✓	✓	✓	✓
O_2 emission	Vol%	✓	✓	✓	✓
Smoke number	FSN	✓		✓	
Oil temperature	deg. C	✓		✓	
cooling water inlet temperature	deg. C	✓		✓	
cooling water outlet temperature	deg. C	✓		✓	
Air temperature after charger	deg. C	✓	✓	✓	✓
Air temperature after cooler	deg. C	✓		✓	
Intake air temperature	deg. C	✓		✓	
Intake air pressure	mbar	✓		✓	
Fuel consumption	g/min	✓		✓	
injection rate	mm3/stroke	✓		✓	
Specific fuel consumption	g/kWh	✓		✓	
Oil pressure	bar	✓		✓	
cooling-water pressure	bar	✓		✓	
Power output	kW	✓	✓	✓	✓
Mean pressure	bar	✓		✓	
Air humidity	%	✓		✓	
Ambient air pressure	mbar	✓		✓	

Figure 2 shows the trap and the configuration of the most important measurement points like trap differential pressure (pressure loss), backpressure, trap inlet temperature, trap outlet temperature and emission measurement. The trap differential pressure has been measured with a special sensor for differential pressure. The distance between the turbocharger outlet and the trap inlet is about 55 cm.

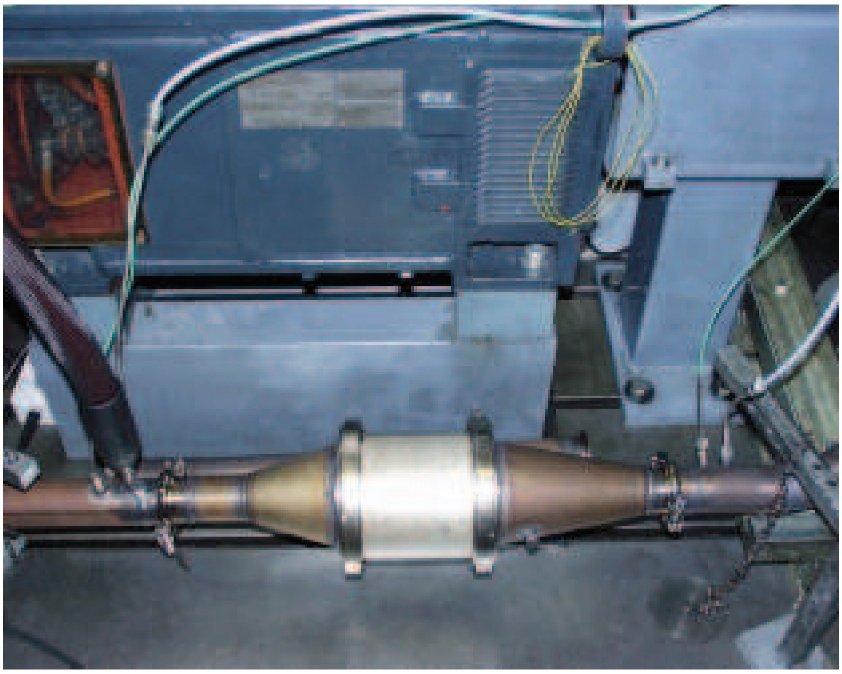

Figure 2: particulate trap at test bench

4 Results of investigation

Table 4.1 contains all investigated fuel borne catalysts and some characteristic values of trap loading and trap regeneration. The TPM load is defined as the difference between trap weights before and after loading procedure. The TPM burn is the difference between the trap weights before and after trap regeneration procedure. The value Ce/C is calculated as follows:

$$Ce/C = \frac{\text{fuel consumption} \bullet \text{Ce concentration} \bullet \text{loading time}}{\text{soot load}}$$

The shown value Ce/TPM is calculated as follows:

$$Ce/TPM = \frac{\text{fuel consumption} \bullet \text{Ce concentration} \bullet \text{loading time}}{\text{TPM load}}$$

Table 4.1: Investigated fuel-borne catalysts and characteristic values of trap loading and trap regeneration

Additive	Ce concentration in fuel [ppm]	Weight of trap before loading procedure [g]	Weight of trap after loading procedure [g]	TPM load [g]	Fuel consumption [kg/h]	Ce consumption [g/7h]	Ce/TPM [%]	Weight of trap after regeneration [g]	TPM burn [g]
Without FBC	**0**	**4386,4**	**4401,6**	**15,2**	**4,08**	**0**	**0**	**4397,6**	**4,0**
Envirox	**3**	**4402,4**	**4419,5**	**17,1**	**4,1**	**0,086**	**0,50**	**4408,0**	**11,5**
Envirox	**5**	**4365,0**	**4381,8**	**16,8**	**4,13**	**0,14**	**0,83**	**4368,4**	**13,4**
Envirox	**10**	**4306,6**	**4323,2**	**16,6**	**4,08**	**0,29**	**1,75**	**4306,0**	**16,6**
Eolys	**10**	**4380,0**	**4394,8**	**14,8**	**4,1**	**0,29**	**1,96**	**4379,6**	**15,2**
Eolys	**25**	**4306,6**	**4322,6**	**16,0**	**4,16**	**0,73**	**4,56**	**4307,2**	**15,4**
CDT	**10**	**4306,4**	**4322,0**	**15,6**	**4,07**	**0,27**	**1,73**	**4307,0**	**15,0**

The mass of TPM inside the trap after a loading time of 7 h varied between 14,8 and 17,1 g. The Ce/TPM ratio was between 0,086 and 4,56.

Figure 3 contains a typical chart of measured trap differential pressure during loading procedure. As can be seen, the trap differential pressure increases nearly linear. Figure 4 shows a typical chart of the trap differential pressure during regeneration procedure.

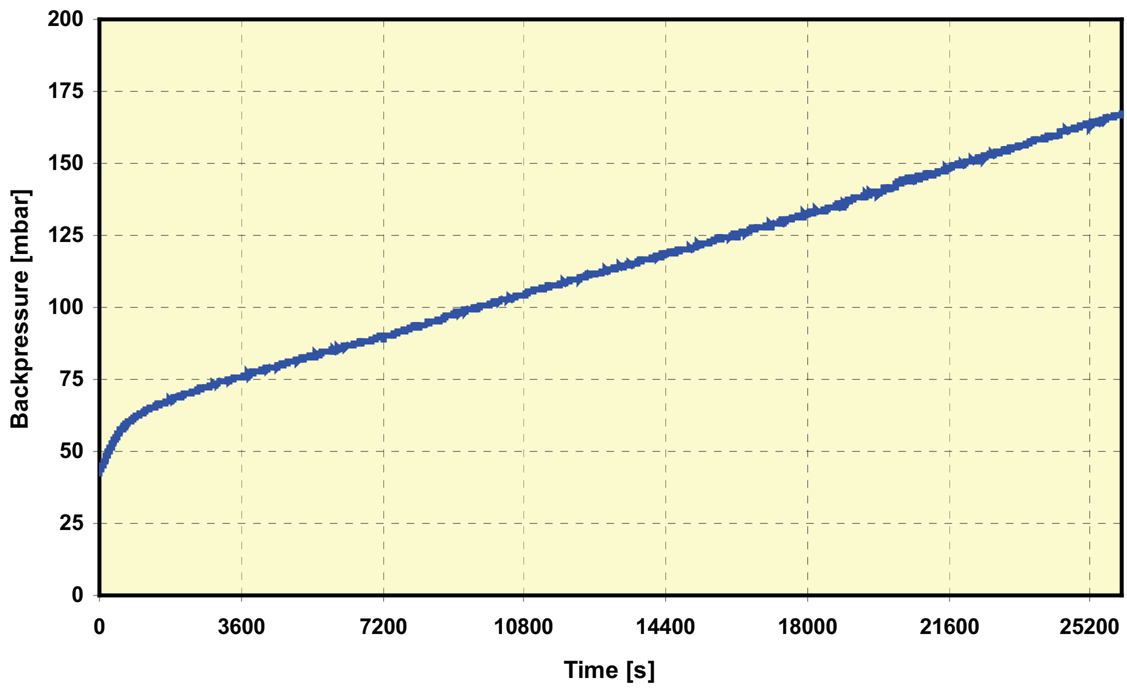

Figure 3: Typical chart of trap differential pressure during trap loading procedure (7h)

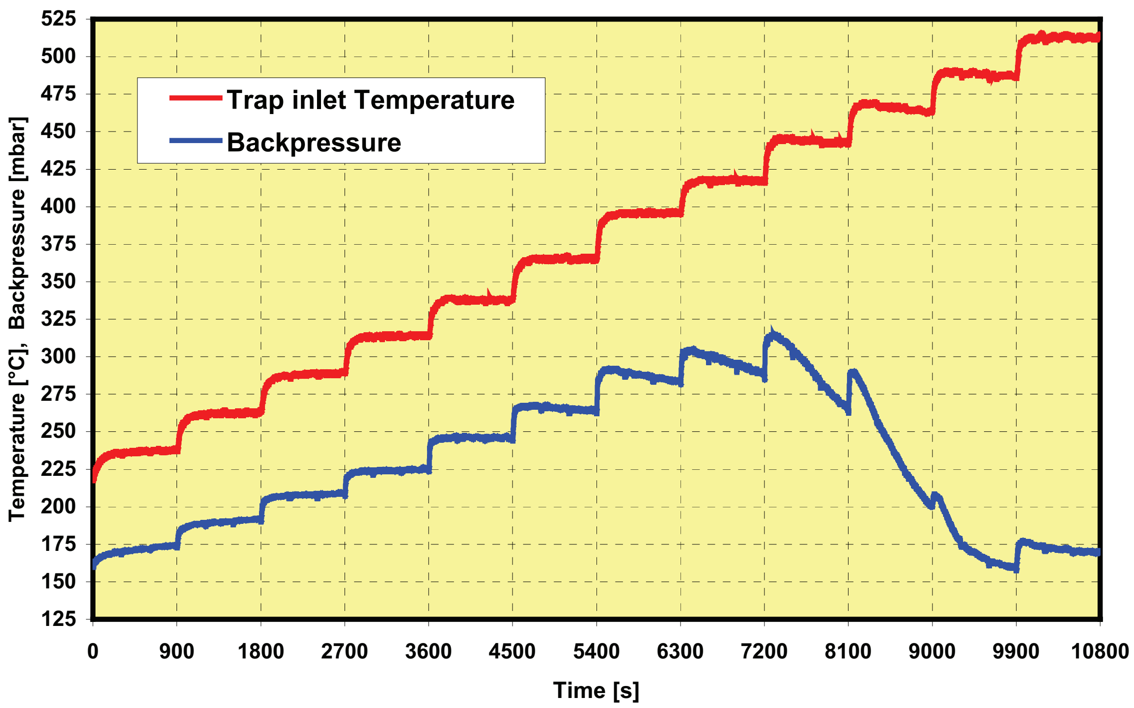

Figure 4: Typical chart of trap differential pressure and inlet temperature during trap regeneration procedure

The behaviour of differential pressure for all measured additives during the loading time is shown in Figure 5. As can be seen, the trap differential pressure increases for all measurements in the same way. The curves differ from each other only in their progressivity. During the loading procedure the differential pressure increases from about 60 mbar to values between 155 and 210 mbar.

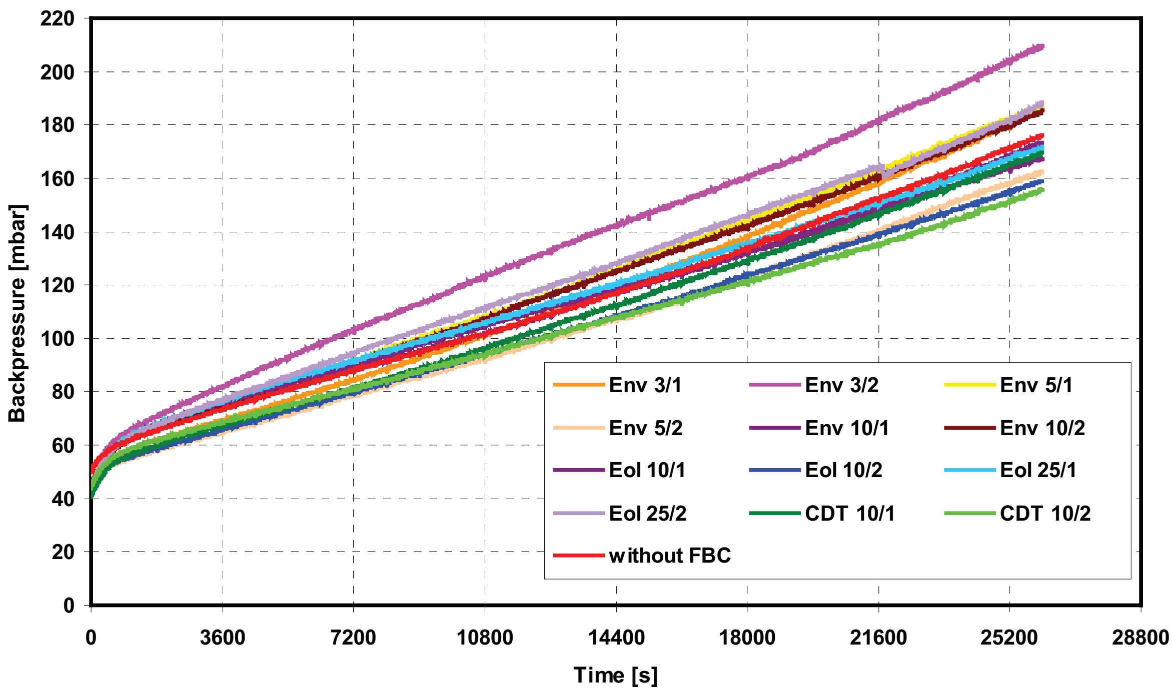

Figure 5: Behaviour of differential pressure during the loading procedure

Figure 6 shows the typical charts during regeneration procedure.

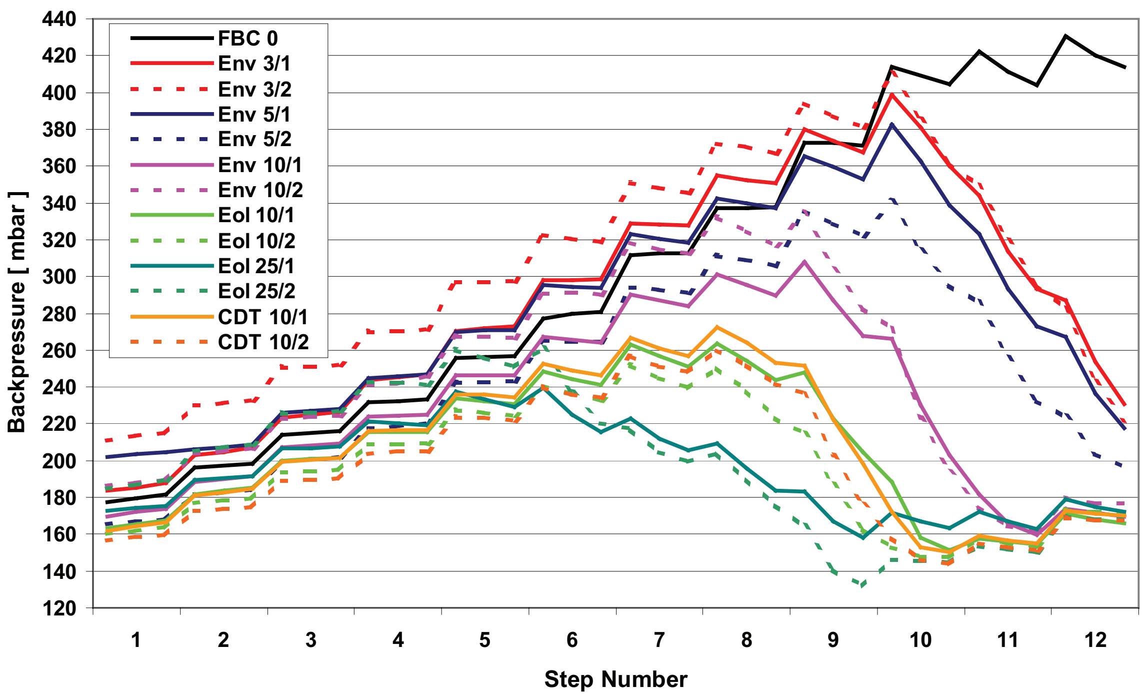

Figure 6: Behavior of differential pressure during the regeneration procedure

Table 4.2 and figures 7 and 8 show a comparison between regeneration rates for the investigated catalysts in dependence of the regeneration temperatures.

Table 4.2: Regeneration Rates for all investigated Fuel-Borne-Catalysts

	Temperature [Deg. C]								
	300	325	350	375	400	425	450	475	500
FBC	RR [mbar/min]								
Envirox 3 ppm Test 1	0,0	0,0	0,0	0,0	0,2	0,9	3,3	5,3	5,7
RR-Temperature [Deg. C]	319	343	370	400	415	445	468	486	510
Envirox 3 ppm Test 2	0,0	0,0	0,0	0,2	0,4	1,2	4,2	5,3	6,0
RR-Temperature [Deg. C]	320	345	370	400	415	448	470	488	515
Envirox 5 ppm Test 1	0,0	0,0	0,0	0,2	0,3	0,9	3,3	5,5	5,1
RR-Temperature [Deg. C]	320	345	370	400	420	450	472	490	512
Envirox 5 ppm Test 2	0,0	0,0	0,0	0,1	0,5	0,8	4,1	4,9	3,5
RR-Temperature [Deg. C]	318	344	370	400	425	448	471	488	513
Envirox 10 ppm Test 1	0,0	0,0	0,0	0,4	1,0	3,2	5,9	2,8	0,4
RR-Temperature [Deg. C]	315	338	366	396	418	445	465	488	514
Envirox 10 ppm Test 2	0,0	0,0	0,0	0,4	1,2	4,1	8,0	2,2	0,3
RR-Temperature [Deg. C]	323	448	370	402	422	445	470	488	415
Eolys 10 ppm Test 1	0,0	0,0	0,3	1,0	1,4	3,8	4,4	0,1	0,3
RR-Temperature [Deg. C]	310	335	365	392	410	435	460	485	510
Eolys 10 ppm Test 2	0,0	0,0	0,8	1,1	2,0	5,2	1,6	0,3	0,1
RR-Temperature [Deg. C]	318	345	371	395	415	438	460	488	515
Eolys 25 ppm Test 1	0,0	0,6	2,0	1,9	2,3	3,4	0,7	0,6	0,5
RR-Temperature [Deg. C]	320	342	366	389	408	432	460	481	511
Eolys 25 ppm Test 2	0,0	0,6	3,2	2,1	2,4	3,5	0,2	0,1	0,0
RR-Temperature [Deg. C]	316	340	365	386	403	430	452	478	504
CDT 10 ppm Test 1	0,0	0,0	0,4	0,7	1,3	4,9	3,7	0,2	0,1
RR-Temperature [Deg. C]	306	332	360	388	405	428	453	480	508
CDT 10 ppm Test 2	0,0	0,0	0,3	0,7	1,6	5,6	2,4	0,3	0,1
RR-Temperature [Deg. C]	315	340	368	390	408	428	456	480	507

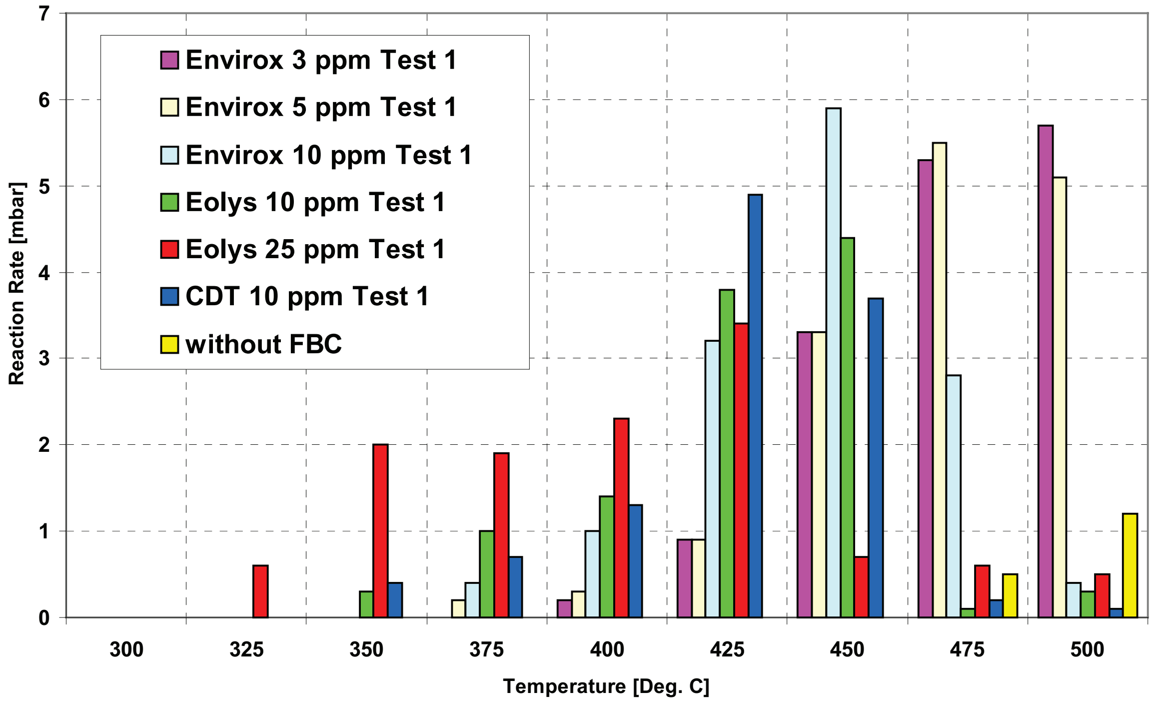

Figure 7: Comparison between Regeneration Rates (Test 1)

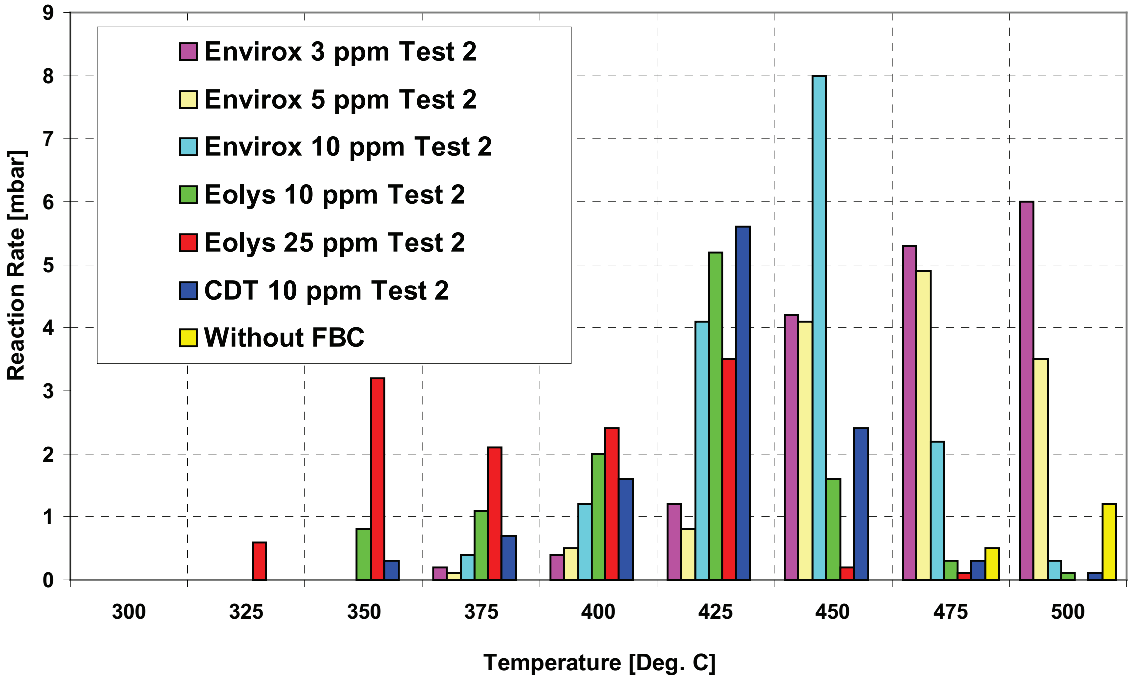

Figure 8: Comparison between Regeneration Rates (Test 2)

The following results were obtained:

By using Envirox with concentrations of 3 and 5 ppm a significant regeneration of the particulate trap only starts above 450 °C. On the other hand the observed regeneration rate at this temperature is very fast compared to other catalysts. For the fuel borne catalyst Envirox a distinct catalytic activity below a temperature of 450 °C only occur for the measured concentrations of 10 ppm. For a concentration of 10 ppm Envirox shows a comparable behaviour as Eolys with 10 ppm and CDT-Pt/Ce with 10 ppm. It is obvious that Eolys with a concentration of 25 ppm shows a very early start of regeneration. Above a temperature of about 350 °C considerable regeneration rates could be observed.

Summarizing the results it could be concluded that a concentration of FBC Envirox of 3 and 5 ppm is to low for a reliable particulate trap regeneration at temperature below 450 °C.

Table 4.3 show a comparison between Regeneration Parameters for the investigated catalysts at the regeneration temperatures.

Table 4.3: Regeneration Parameters for all Fuel-Born-Catalysts

FBC	Regeneration				
	Balance Point	Burn Of	RRmin	RRmax	T. RRmax
	deg. C	deg. C	mbar/min	mbar/min	deg. C
Envirox 3 ppm Test 1	400	415	0,2	5,7	510
Envirox 3 ppm Test 2	370	400	0,2	6,0	515
Envirox 5 ppm Test 1	370	400	0,2	5,5	490
Envirox 5 ppm Test 2	370	400	0,1	4,9	488
Envirox 10 ppm Test 1	366	396	0,4	5,9	465
Envirox 10 ppm Test 2	370	402	0,3	8,0	470
Eolys 10 ppm Test 1	335	365	0,1	4,4	460
Eolys 10 ppm Test 2	345	371	0,1	5,2	438
Eolys 25 ppm Test 1	320	342	0,5	3,4	432
Eolys 25 ppm Test 2	316	340	0,1	3,5	430
CDT 10 ppm Test 1	332	360	0,1	4,9	428
CDT 10 ppm Test 2	340	368	0,1	5,6	428

The highest temperature for balance point was found for Envirox 3 ppm. A complete regeneration (PM burn rate: 100 %) was reached for Eolys 10 and 25 ppm, Envirox

10 ppm and CDT 10 ppm. The highest regeneration rate (8 mbar/min) was found for Envirox 10 ppm at 470 deg. C.

Figure 9 shows the comparison between specific fuel consumptions without FBC and without trap (original fuel consumption), without FBC and with trap and with all investigated FBC‘s and with trap. For all realised tests the increase in fuel consumption was between 0,5% and 3% in maximum.

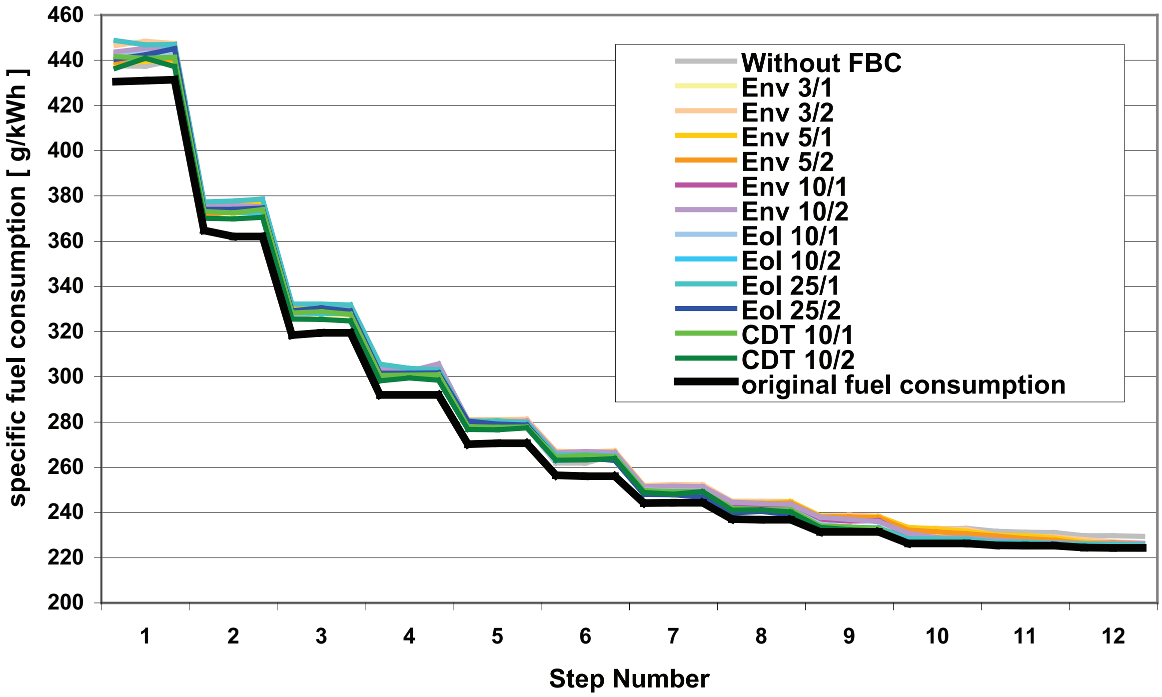

Figure 9: comparison between specific fuel consumptions

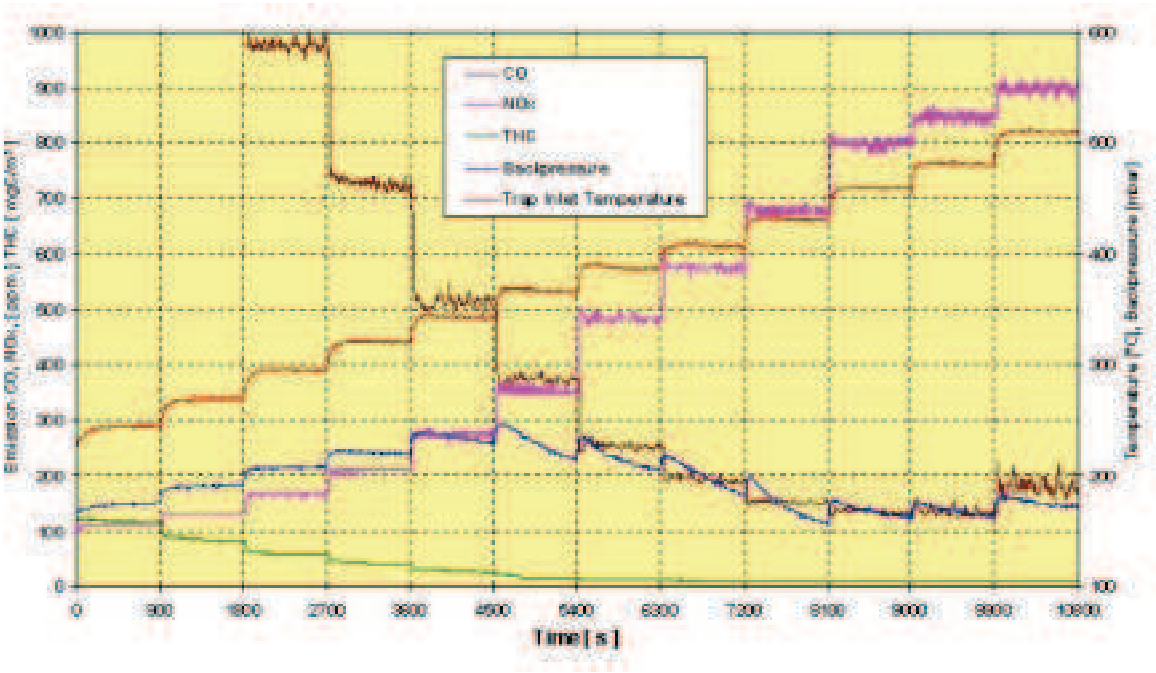

Figure 10: Typical chart for the emission of exhaust components

In figure 10 a typical chart for the emission of the exhaust components could be seen. For all measurements the amount of emission values were nearly the same. The measured emission values for all tests could be find at the attached CD (directory “results”).

5 Conclusion

The regeneration behaviour of 3 fuel-borne catalysts were investigated at a PSA diesel engine with a SIC particulate trap.

The mass of TPM inside the trap after a loading time of 7 h varied between 14,8 and 17,1 g. The Ce/TPM ratio was between 0,086 and 4,56.

During the loading procedure the differential pressure increased from about 60 mbar to values between 155 and 210 mbar.

By using Envirox with concentrations of 3 and 5 ppm a significant regeneration of the particulate trap only starts above 450 °C. On the other hand the observed regeneration rate at this temperature is very fast compared to other catalysts. For the fuel borne catalyst Envirox a distinct catalytic activity below a temperature of 450 °C only occur for the measured concentrations of 10 ppm. For a concentration of 10 ppm Envirox shows a comparable behaviour as Eolys with 10 ppm and CDT-Pt/Ce with 10 ppm. It is obvious that Eolys with a concentration of 25 ppm shows a very early start of regeneration. Above a temperature of about 350 °C considerable regeneration rates could be observed.

Summarizing the results it could be concluded that a concentration of FBC Envirox of 3 and 5 ppm is to low for a reliable particulate trap regeneration at temperature below 450 °C.

The highest temperature for balance point was found for Envirox 3 ppm. A complete regeneration (PM burn rate: 100 %) was reached for Eolys 10 and 25 ppm, Envirox 10 ppm and CDT 10 ppm. The highest Regeneration Rate (8 mbar/min) was found for Envirox 10 ppm at 470 deg. C.

Index of figures and tables

Index of enclosure

Content of CD

The CD contains 3 directories:

1. Report
2. Measured_Value
3. Results