

## **Experiences of Retrofit Particulate Filters for Diesel City Buses and Passenger Cars**

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### **Abstract**

*In this project the reduction potential of retrofit by diesel particle filter (DPF) was evaluated regarding particulate emissions, and experiences were collected for their large scale introduction. Partial flow and wall flow working, continuously regenerating trap (CRT) from different manufacturers were investigated on articulated city buses manufactured by IKARUS and powered by six-cylinder, direct injection, 160 kW Euro-II RÁBA engine. The emissions were measured according to the Regulation ECE-R-49.02, besides gravimetric method the particulate number and size distribution were measured too. In real life bus operation the smoke emission, the noise level, and acceleration were tested before and after retrofitting, and continuously the backpressure before the DPF and its inlet exhaust gas temperature were monitored by a data logger. A large reduction of the particulate emissions (90-95%) could be achieved by the wall flow DPF-s. The degrees of decrease were the same in case of gravimetric and particle number measurements. The CO and HC emissions were also effectively (by 85-95%) reduced.*

*The tested passenger car was a EURO-4 level Opel-Astra, in this case only partial flow CRT were investigated according to Regulation ECE-R-83.04. The reduction of the particulate emissions was between 20-40%. The noise level measured outside of the test vehicles remained unchanged. The reliable operation of wall flow type DPF can be controlled by the continuous measurement of the back-pressure. No remarkable increase of the fuel consumption and decrease of the power were recognised after the retrofitting. Follow up field tests are going on city buses to evaluate the durability of CRT.*

**Keys-words:** *diesel vehicle, particulate emissions, particulate filters, retrofitting, emission measurements, particle measurements, gravimetric analysis, number/size distribution.*

### **Introduction**

Diesel engines are at present the most fuel efficient and durable power plants of road vehicles. Due to the effective combustion process their CO, HC and CO<sub>2</sub> emissions as well as their fuel consumption are very low but their particle and NO<sub>x</sub> emissions are high. The motivation for retrofits of diesel particulate filters (DPF) in case of city buses and passenger cars is given on the one hand by the serious air polluting and health effects caused by the fine particulate matters, while on the other hand by the increasing share of old vehicles in vehicle fleets of Hungary.

Recently the issue of fine particles from diesel fuelled road vehicles has become an increasing importance. According to the results of several experts [Kittelson, 2008] [Mayer, 2005] the fine particles (diameter<10µm, PM10 and especially the ultrafine particles d<100nm) are provable injurious to the human health. Based on these findings important research was made in the last two decades to develop reliable and efficient particulate filters for diesel vehicles.

The basic objective of this project was to evaluate the potential of retrofit by DPF in reduction of particulate emissions, and to prepare a strategy for large scale introduction of retrofit DPF for the Hungarian road vehicle fleets especially in low emission zones.

Ordered by the Hungarian Ministry of Transport, Communication and Energetics KTI investigated in cooperation with DPF manufacturer and the Budapest Transport Company the on the market. available DPFs on typical diesel vehicles of the Hungarian fleets. The main results of laboratory tests and first real life measurements on city buses and passenger cars are discussed in this paper.

## **1. Background for retrofit of DPF in Hungary**

Road traffic is one of the main sources of the air polluting particle emissions in Hungary. Similarly as the EU Hungary have mandatory, health-based air quality limit values for the most important air polluting materials. Those are difficult to meet in our big cities especially in the capital are values for PM<sub>10</sub> and NO<sub>x</sub>. The limit values for the yearly average and the development of the Budapest monthly average values measured by one of the air quality monitoring stations being on the Kosztolányi square in Budapest are shown in Figure 1. The evaluated period of time is between 2004 and 2009, the air polluting materials are PM<sub>10</sub>, NO<sub>x</sub> and NO<sub>2</sub>. The number of exceeding of the daily average limit value for PM<sub>10</sub> in case of all air quality monitoring stations of Budapest can be seen in Table 1. from calendar year 2004 till 2008. The daily average limit value for PM<sub>10</sub> (50µg/m<sup>3</sup>) may not to be exceeded more than 35 times per year, but it was unfortunately widely exceeded in most of the monitoring stations. In order to meet the PM<sub>10</sub> limit values the decrease of the particle emissions of road vehicles is required by all means.

To decrease the particulate emissions in the Hungarian big cities first of all the following road vehicle categories have to be taken into consideration: diesel fuelled passenger cars, light duty trucks and city buses. The share of diesel fuelled cars in the car fleet was between 15-17% during the last 3 years but their yearly mileage is 2-3 times bigger compared to the petrol fuelled ones. The dominant part of light duty trucks is diesel fuelled. The potential for retrofit DPF in case of city buses can be seen in table 2. The vehicles belonging to the pre Euro and to the Euro -1 emission categories must not be taken into consideration due to their high age and being near to their scrapping. The high share of vehicles belonging to the Euro-2/3 emission categories may be led back to the first registration of imported used cars/light duty trucks/buses.

The above mentioned information was the basis for the necessity of measures to decrease particle emissions of the existing road vehicle fleets consequently for the evaluation of large scale use of retrofit DPF.

## **2. Methodology of tests and measurements**

### **Test vehicles**

The particle filters for buses were tested in first step on engine test bench according to regulation ECE-R49.02 and ECE-R24.. Most of the filters were tested with the same diesel engine (Rába D10 UTSSL 160, Euro-II). The main parameters of this engine are the following: displacement 10349 cm<sup>3</sup>, a maximum effective power 160 kW (at revs of 1900 r/min) and maximum effective torque 955 Nm (at revs of 1200 r/min). The filters tested on this engine will be investigated in the second, follow-up phase of the project on city buses having the same type of engine. The DPF designed for VOLVO-made Euro-III level city buses , was tested with another engine (Rába D10 TLL 225, Euro-III), because no Volvo-made bus engine was available during the bench tests. The parameters of this engine are as follows: displacement 10349 cm<sup>3</sup>, a maximum effective power 240 kW (at revs of 2100 r/min) and a maximum effective torque 1260 Nm (at revs of 1500 r/min). The parameters of the IKARUS-made city bus are the following: type Ikarus 280.40, having the same Rába D10 UTSSL 160 engine as that on bench tested one.

These buses are articulated ones, have ZF 4HP 500 automatic gear-box with 4+1 gears, a net weight of 14300 kg and a gross weight of 24890 kg. These buses had been built between 1986 and 1993 (the fleet this type consist of 50-buses at the Budapest Transport Company BKV), but all these buses

went through a rebuilding in the middle of the nineties. All the test filters are retrofit into this series (also for their comparability), except the two Volvo-made bus filters, which are to be installed into Volvo 7700A buses of the BKV's fleet. Volvo 7700A buses have a diesel engine (Volvo D7C 275 HS, Euro-III) with a piston displacement of 7300 cm<sup>3</sup>, a maximum effective power of 202 kW and a maximum effective torque of 1200 Nm. These are articulated buses too; they were produced between 2004 and 2006, and have ZF 5HP 592 automatic gear-boxes with 5+1 gears, a net weight of 17440 kg and a gross weight of 28000 kg. For testing the particle filters produced for passenger car the test car was an Opel Astra G 1.7 DT and the tested light duty truck was a Renault Traffic T42B.

The Opel Astra - which had been produced in 2006 - has a diesel engine with a displacement of 1686 cm<sup>3</sup>, a power of 59 kW and it belongs to the emission category Euro 4. The car has a 5+1-gear manual gear-box, a net weight of 1205 kg and a maximal gross weight of 1745 kg. The Renault Traffic - which had been produced in 1994 - has a diesel engine with a displacement of 1499 cm<sup>3</sup>, a power of 62 kW and its emission category is Euro-1. This light duty truck has a 5+1-gear manual gear-box, a net weight of 1490 kg and a maximal gross weight of 2650 kg. The diesel fuel used for the engine tests as well as during the field tests was commercial one having low sulphur content (S<10ppm).

### **Tested retrofit particle filters**

Regarding the mode of operation all of the tested DPF have passive regenerations using NO<sub>2</sub> and catalysed filter that is they belong to the catalysed continuously regenerating trap systems (CCRT). In case of the city buses wall flow (full flow) and partial flow DPF were tested, in case of the passenger car and the light duty truck only partial flow DPF were used. The substrates were depending on the manufacturer ceramics honeycomb structure and foam, sintered metal. In case of the city bus the original silencer was replaced by the DPF. Figure 2. shows the setting of the original silencer, and. the fitting in of DPF made by BAUMOT.

### **Test methods and equipments**

The measurements of DPF's for city bus engines were made according to the Regulations ECE-R-49.02 and ECE-R24 on engine test bench that is the 13-mode steady-state procedure and full load/free acceleration tests were made. The measurements of DPF's for passenger car and light duty vehicle were carried out according to the Regulation ECE-R-83.05 which means driving cycle tests on a chassis dynamometer. In both cases full flow dilution tunnel and PDP pump were used. The emission measurements were made by the Pierburg AMA 2000 exhaust gas analyser system. The smoke emissions were measured at free acceleration according to the ECE-R-24. regulation using the Opacimeter type 439 made by AVL.

For measurement of fine particles a condensation particle counter CPC 3022A type made by TSI and the size spectrum by a GRIMM made 1.109-type spectrophotometer were used.

The effects of the DPF on the engine of the retrofitted vehicle were evaluated by measurements of the back pressure downstream before the silencer, DPF respectively in case of passenger car at v=100km/h and full load on chassis dynamometer in case of the city buses at acceleration with full load and at 50km/h speed. Beside the back pressure the acceleration times were registered at acceleration on full throttle between two values of speeds.

The continuous operation of DPF is controlled by CPK made DYNTEST AML data logger system which monitors the back pressure and inlet temperature of DPF. The monitored data are evaluated by special software.

## **3. Results of the tests**

### **DPF for city buses**

Table 3. shows the main parameters and efficiencies of emission reductions calculated from the results of engine test bench measurements for all of the tested DPF. The CO and HC emissions were reduced in average 70-90% by the investigated CRT-DPF due to application of the oxidation catalyst. The reduction of NO<sub>x</sub> is not significant.

The particulate emissions were reduced in case of wall flow type DPF by 90-94% measured at the 13-Mode Test and by 94-99% measured at free acceleration. The reduction of the particulate emissions in case of partial flow type DPF were 46-60% measured at the 13-Mode Test and 22-63% measured at free acceleration.

The measured values without and with the BAUMOT made DPF are shown in Table 4. It has to be highlighted that the reduction of particle numbers (fine particles) is much bigger than that of the particle emission measured gravimetric technique.

The same conclusion can be drawn on the basis of Figure 5., where the numbers of particles are shown separately for each mode of the 13-mode test. Figure 3. shows the development of back pressure and exhaust gas temperature at the inlet of DPF as well as the surface temperature of the DPF in real life operation. Figure 4. shows the frequency distribution of back pressure and exhaust gas temperature at the inlet of DPF. On the basis of the development and frequency of the back pressure one can conclude that the DPF is working well.

### **DPF for passenger car and light duty vehicle**

Table 5 shows the main parameters and efficiencies of emission reductions calculated from the results of the driving cycle measurements. Where no value is given there no measurable change could be measured. It has to be mentioned that all of the investigated DPF were partial flow type. The reduction of CO and HC emissions is fluctuating remarkably between 20-75% depending on the operation of the oxidation catalyst. No definite change in the NO<sub>x</sub> emission could be determined. The particulate emissions were reduced in case of the driving cycle tests 20-45% and 17-50% measured at free acceleration depending on the mileage. The increase of the mileage resulted in the decrease of PM emission measured by gravimetric method.

### **Conclusions**

In this project the efficiencies of emission reduction, reliability of retrofit DPF for city bus, passenger car and light duty truck were evaluated in laboratory according to the UN-ECE and EU emission regulations as well as in real life operation.

On the basis of the test results and experiences of real life operation it can be expressly declared that in case of engines being in good technical condition the retrofitting of DPF enables an effective decrease of the particle emission ( in case of wall flow type DPF the particle emission practically was ceased ). The retrofit of DPF is realisable both technically and economically. The retrofit and operation of DPF having good efficiency needs however a careful preparation and a good-organised maintenance of the engine. The reduction of particle emissions in case of wall flow kind DPF can be evaluated reliably only on the basis of counting and size distribution of particles. The function of DPF in real life can be well monitored on the basis of the back pressure downwards to it.

It has to be mentioned that as soon as the Euro-6 emission level will introduced, the majority of the engines of the buses will be equipped with DPF. One can reckon with this within 2-3 years, thus the retrofitting of the filters can be regarded as the preparatory process of the introduction of the new cleaning technology of exhaust gases.

The tests of passenger car have shown that only the retrofit of partial flow filters can be economically justified. This kind of DPF improves of the particle emissions usually only by one emission category (for example: instead of Euro-2 it will fulfil Euro-3 emission level).

Regarding the home introduction of the DPF on the basis of the test results the following conclusions and proposals can be made: The retrofitting of the DPFs can be considered as efficient and reliable mean for the decrease of particle emissions especially that of the fine particles. They have already been put into practice in several countries with favourable results. The criterion of the large scale home introduction of retrofit DPF are the elaboration of unified qualification, government control system and the supporting strategy.

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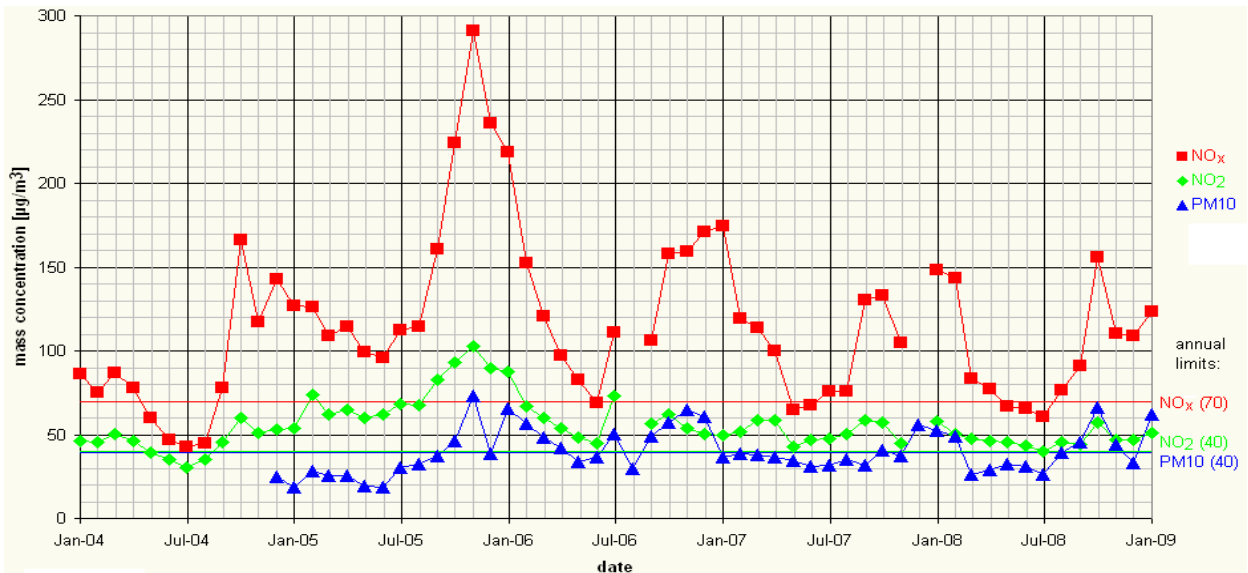


Figure 1: Monthly average values of PM10 and NOx/NO2 on Kosztolányi Square, Budapest XI. Source of data: Hungarian Air Quality Monitoring System (station "BP6 Kosztolányi")



Figure 2: Rába D10UTSLL160 diesel engine with the original silencer (left) and with Baumot BA1012 particle filter (right) in a bus of Ikarus 280.40 type

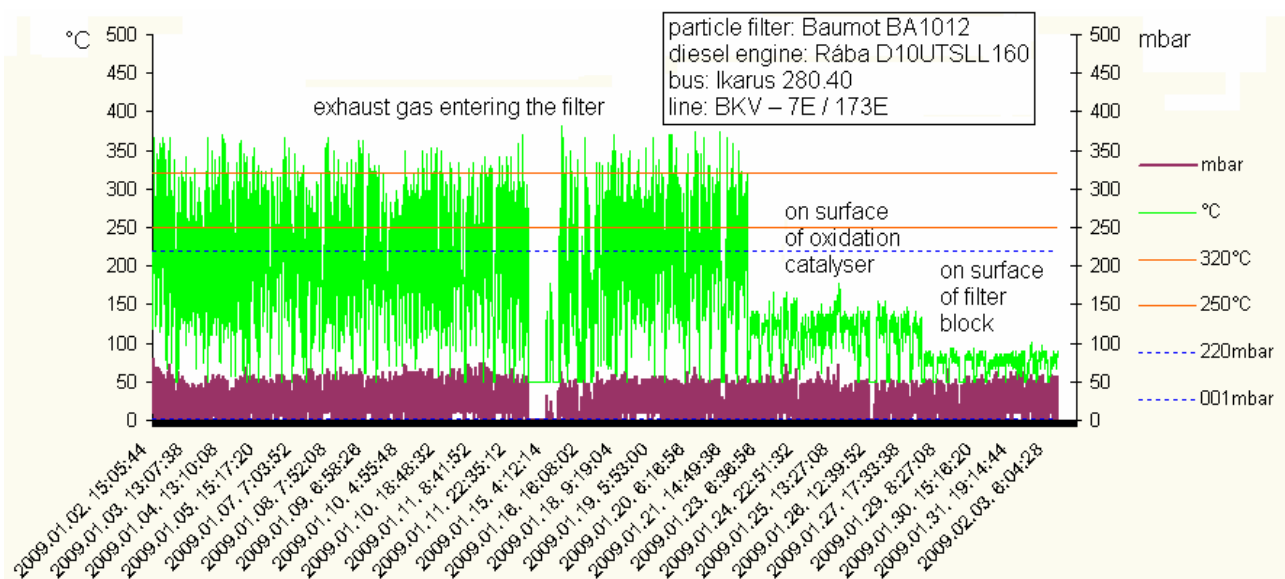
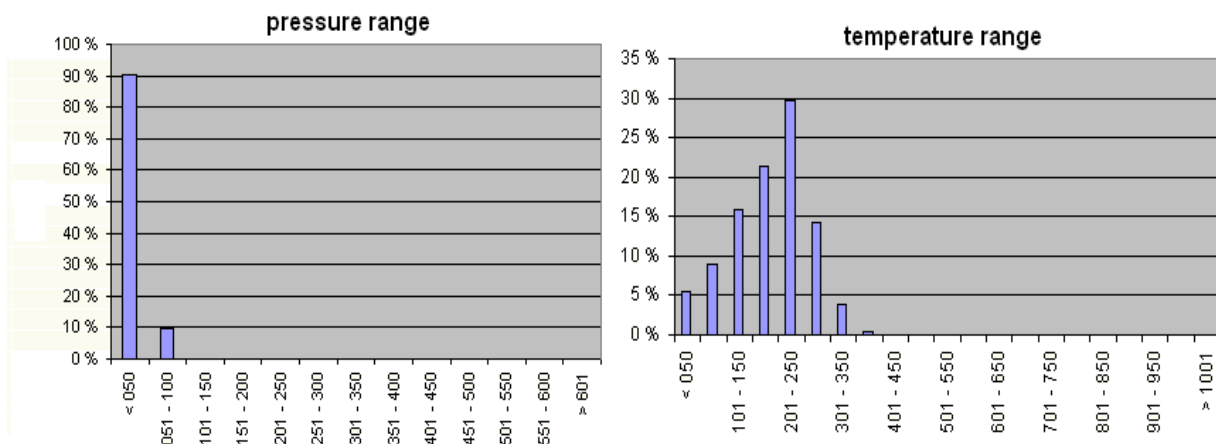


Figure 3: Exhaust back pressure, exhaust gas temperature and surface temperatures of diesel particle filter, profiles measured during bus operation

Control Box: Dyntest v3.09  
No. 17215

particle filter: Baumot BA1012  
diesel engine: Rába D10UTSLL160  
bus: Ikarus 280.40  
line: BKV - 7E / 173E  
date range: 30.12.2008-21.01.2009



Average Pressure	22 mbar	Average Temperature	188 °C
Maximum Pressure	108 mbar	Maximum Temperature	406 °C
Percentage < 1 mbar	0,0 %	Percentage > 250 °C	18,6 %
Longest duration >220 mbar	0:00:00 hh:mm:ss	Longest duration >320 °C	0:02:40 hh:mm:ss
Frequency of 120 seconds above 220 mbar	0 times	Frequency of 120 seconds above 320 °C	1 times

Figure 4: Histogram of exhaust back pressure and exhaust gas temperature at particle filter entrance in an urban bus, measured during bus operation

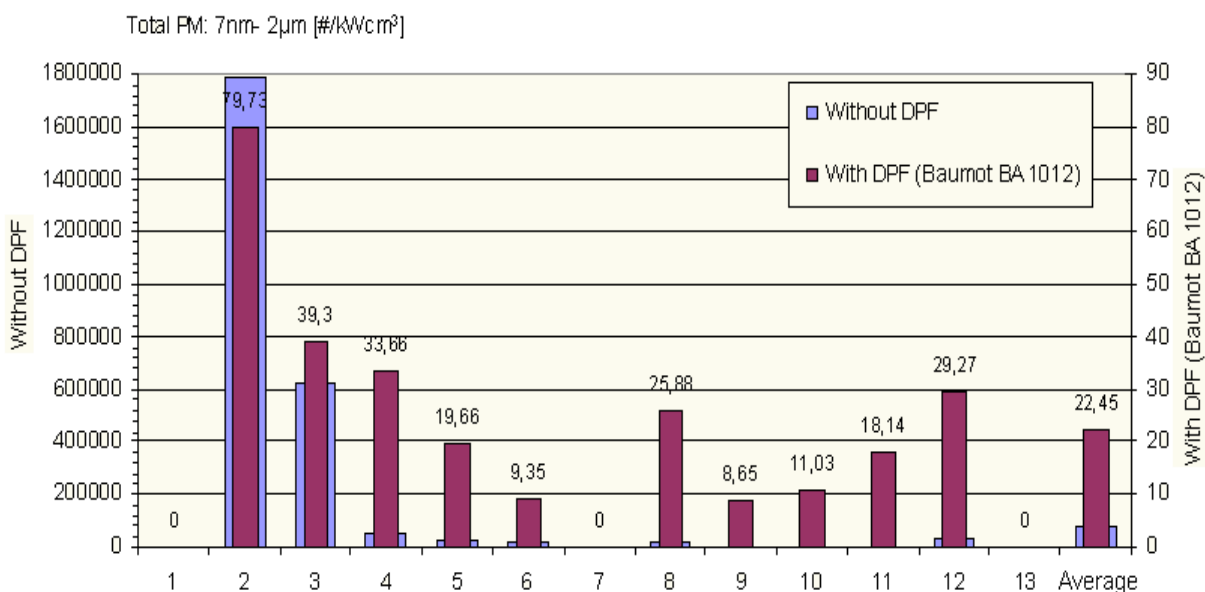


Figure 5: Particle emission without and with wall flow DPF (type: BAUMOT BA1012) (measured according to ECE R-49.02.)

Limit value	55 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>	50 µg/m <sup>3</sup>
Year	2004	2005	2006	2007	2008
<i>Measuring station</i>					
Gilice Square Budapest XVIII	25	<b>107</b>	<b>71</b>	<b>43</b>	<b>46</b>
Széna Square Budapest I	<b>90</b>	24	33	9	32
Baross Square Budapest	<b>149</b>	<b>133</b>	<b>90</b>		
Pesthidegkút Budapest II	<b>54</b>	<b>76</b>	<b>46</b>	13	1
Kőrakás Park Budapest XV	<b>49</b>	<b>115</b>	<b>163</b>	<b>96</b>	<b>74</b>
Kosztolányi D. Sq. Budapest XI		<b>55</b>	<b>152</b>	<b>68</b>	<b>90</b>
Honvéd Sp. Centre Budapest XIII	<b>115</b>	<b>136</b>	<b>160</b>	<b>106</b>	<b>39</b>
Erzsébet Square Budapest V	<b>48</b>	<b>164</b>	<b>153</b>	<b>117</b>	<b>49</b>
Gergely Street Budapest X			<b>76</b>	<b>43</b>	<b>30</b>
Nagytétényi Road Budapest XXII		<b>83</b>		<b>61</b>	<b>97</b>
Szt. István Road Budapest XXI				<b>102</b>	<b>64</b>
Teleki Square Budapest VIII					<b>52</b>
<i>Allowed occurrence for limit exceeding days during a calendar year: 35.</i>					
<b>Data over the allowed occurrence level signed with bold.</b>					
Data availability between 100-90%.					
Data availability between 90-75%.					
Data availability between 75-50%.					
Not to evaluate (data availability less than 50%).					
The component not measured.					

Table 1: Annual occurrences of 24-hour limit exceedings for PM10, at air pollution measuring stations of Budapest

bus data						engine data			
bus type	gross weight [kg]	net weight [kg]	average age [year]	fleet [db]	fleet [%]	engine type	emission rating	displ. [cm <sup>3</sup> ]	power [kW]
Ik 260, Ik 280	17890/24890	9650/14300	20	105	7,3	Rába D2156 HM6U	Euro 0	10350	141
Ik 260, Ik 280	17890/24890	9650/14300	18	44	3,1	Rába D2156 MT6U	Euro 0	10350	164
Ik 260	17890	9650	15	1	0,1	Rába D2356 HM6U	Euro 0	10688	176
Ik 260, Ik 280	17890/24890	9650/14300	16	179	12,5	Rába D10 UTS 150	Euro 0	10350	150
Ik 415	16200	9950	15	130	9,1	DAF LT 160G	Euro 0	11630	160
				<b>459</b>	<b>32,0</b>				
Ik 260, Ik 280	17890/24890	9650/14300	16	370	25,8	Rába D10 UTS 155	Euro 1	10350	155
Ik 415	16200	9950	14	39	2,7	DAF LT 160L	Euro 1	11630	160
Ik 415, Ik 435	16200/24550	9950/14300	13	169	11,8	DAF LT 195L	Euro 1	11630	198
				<b>578</b>	<b>40,3</b>				
Ik 280.40	24890	14300	14	50	3,5	Rába D10 UTSLL 160	Euro 2	10350	160
Ik 435	24550	15100	11	1	0,1	Rába D10 UTSLL 190	Euro 2	10350	190
Ik 415	16200	9950	11	1	0,1	DAF GS 160M	Euro 2	11630	160
Ik 435	24550	15100	11	1	0,1	DAF GS 200M	Euro 2	11630	200
Ik 412	17400	10600	7	114	7,9	MAN D 0826 LOH 17	Euro 2	6871	164
Ik 435	24550	15100	11	1	0,1	MAN D 2865 LUH 07	Euro 2	11970	230
Ik 405	8330	5200	12	80	5,6	Perkins AL 81072	Euro 2	3980	101
				<b>248</b>	<b>17,3</b>				
Volvo	28000	17440	2	150	10,4	Volvo D7C 275 HS	Euro 3	7300	202
Irisbus Agora	28500	17080	6	1	0,1	Iveco Cursor 8	Euro 3	7790	200
				<b>151</b>	<b>10,5</b>				
Ik = Ikarus				<b>total:</b>	<b>1436</b>				<b>100,0</b>

Table 2: Composition of bus fleet of BKV Transport Company in August 2007

product	type	construction	particle filter			emission reduction [%]				
			principle	mass [kg]	back pressure* [mbar]	NO <sub>x</sub>	CO	HC	PM	smoke**
DCL	3150-FF-5S55-21	honeycomb	full flow	28,7	187	9,3	91,3	88,9	91,5	99,1
DCL	3150-DQ-AS12-X4		partial flow	18,9	123	6,1	90,0	81,0	46,6	21,7
DCL	9582-FF-5C55-21	honeycomb	full flow	60,5	151	0,6	92,4	83,3	90,0	96,0
DCL	B416-SF-BN12-X3		partial flow	44,7	167	1,8	80,4	66,7	61,4	62,8
HJS	94622034	sinter metal	full flow	58,0	128	4,2	84,4	94,1	92,9	93,2
Remus	B12		partial flow	48,7	115	4,2	85,1	77,8	58,5	56,5
GAT Eurokat	DPX1 870.30850 I. prototyp.	honeycomb	full flow	37,6	167	4,8	86,1	88,9	88,6	93,5
GAT Eurokat	870.01.30850 II. prototyp.	ceramic foam	partial flow	35,6	273	4,5	80,2	77,8	58,1	43,9
GAT Eurokat	870.01.30850 III. prototyp.	ceramic foam	partial flow	35,2	309					30,1
Baumot	BA1012	honeycomb	full flow	15,5	160	4,8	86,1	88,9	88,3	99,3
Volvo **	70330450		full flow	29,2	213	-0,9	70,0	80,0	93,6	96,8

\* maximal value measured at ECE-R24  
\*\* at free acceleration

Table 3: Parameters and engine test results of CRT particle filters for urban buses (test engine: RÁBA D10 UTSL 160 and RÁBA D10 TLL225)

	CO [g/kWh]	CH [g/kWh]	NO <sub>x</sub> [g/kWh]	NO <sub>2</sub> [g/kWh]	PM gravimetric [g/kWh]	PM fine [#/kWcm <sup>3</sup> ]	Smoke [m <sup>-1</sup> ]
<b>Without DPF</b>	<b>1,01</b>	<b>0,18</b>	<b>6,66</b>	<b>0,87</b>	<b>0,06915</b>	<b>72036,3</b>	<b>0,301</b>
<b>With DPF</b>	<b>0,14</b>	<b>0,02</b>	<b>6,34</b>	<b>1,79</b>	<b>0,00806</b>	<b>22,32</b>	<b>0,002</b>
<b>Limit values:</b>							
<b>Euro 2</b>	<b>4</b>	<b>1,1</b>	<b>7</b>		<b>0,15</b>		
<b>Euro 3</b>	<b>2,1</b>	<b>0,66</b>	<b>5</b>		<b>0,1</b>		<b>0,8</b>

Table 4: Summarized results of the bench tests made on DPF manufactured by BAUMOT

tested vehicle	product	tye	construction	principle	mass [kg]	back pressure without / with filter [mbar]	particle filter								mileage at time of measurement [km]	
							cold cycle				emission reduction [%]					
							NO <sub>x</sub>	CO	HC	PM	NO <sub>x</sub>	CO	HC	PM	smoke***	
Opel Astra 1.7 CDTI	Remus RFK2	partial flow	3,56		151 / 303*	-21,7	60,0	58,3	27,7	0,4	42,9	34,6	36,0	base test		
					297*	2,2	20,0	27,7	-3,8	16,7	19,0	25,6	1000			
					281*	6,5	20,0	26,1	8,1	28,6	31,9	32,1	3300			
					284*	8,5	36,8	21,1	29,0	3,2	18,2	28,6	36,3	7600		
					328*	-19,9	61,5	42,9	15,7	6,5	50,0	20,9	30,4	13500		
	Remus RFK1	partial flow	2,97			328*	-4,7	40,0	25,0	43,8	4,2	44,9	51,2	base test		
						389*	-9,6	50,0	22,2	7,7	-4,1	23,7	18,7	1000		
						396*	22,0		29,6	20,8		17,1	17,0	3000		
						286*	-12,9		25,2	-6,5		30,1	41,8	base test		
						281*	-2,5		23,7	1,2		30,3		550		
HJS DPF-08	without catalyser	partial flow	7,15		323*	-6,4		13,8	-1,2		19,3	26,1	16500			
					281*	-15,0		23,8	0,4		26,1	39,1	6500			
Renault Traffic	DCL	B407-SF-AS07-X3	with catalyser	partial flow		197 / 203**	1,1	75,6	52,1	43,0	3,0	81,9	59,8	41,6	50,5	base test
						223**	4,9	66,7	41,3	40,8	3,7	70,6	43,9	39,2	33,3	6200

\* maximum value measured at full load (v = 100 km/h)  
\*\* maximum value measured at full load (v = 90 km/h)  
\*\*\* at free acceleration

Table 5: Parameters and European driving cycle test results of CRT particle filters for passenger car and light duty truck