RETROFITTING OF URBAN BUSES IN ISRAEL WITH PARTICULATE TRAPS – FIRST RESULTS

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ABSTRACT

The main objective of the presented work was to evaluate the possibility of reducing particulates emissions from urban buses in realistic Israeli driving conditions by retrofit with diesel particulate traps.

Selection of particulate trap type and estimate of particulates reduction potential were performed based on the experience gained in Switzerland, mainly in the framework of the VERT project. Based on the VERT findings, continuously regenerating trap (CRT) was selected for retrofit installation on two urban buses in Israel, equipped with Euro 2 diesel engines.

The buses with the CRT have accumulated, till now, about 60,000 km of traveled distance. During the tests, no registered reclamations of the bus drivers or maintenance technicians have been noted. Periodic measurements of backpressure have not indicated any sensible increase of the pressure.

Low temperatures of the exhaust gases were monitored on few city center routes, due to the low speed of the buses. This might pose a problem regarding the CRT regeneration in winter season, when the air conditioning system is not operated and the engine load is lower.

INTRODUCTION

The problem of abatement of diesel particulates emissions is considered now as one of the main challenges in the quest for better air quality. Although the first attempts for using diesel particulate traps (PT) and catalytic converters were already made in the sixties, the development of advanced diesel exhaust control devices based on novel processes and materials still remains a scientific and engineering challenge. A successful development will enable to meet future limits of particulate emission. The European Union (EU) has reduced the limiting values of Particulate Matter (PM) in the year 2005 by a factor of 5 compared to the EURO 3 values. It is expected that most of the new vehicles will have PT's as original equipment. These emission targets and retrofitting projects have triggered development activities in the industry. It could be forecasted that, at the latest in 2007/8, substantially less expensive traps will be commercially available in large quantities, to meet the growing demands.

Several large retrofitting projects are in progress or planned worldwide, [1]. Berlin and Paris have already retrofitted thousands of buses. Sweden is deploying more than 3,000 traps in its "environmental zones" at Stockholm, Goteborg and Malmö. New York plans to spend $250 million on the "cleanest bus fleet in the world". California is even more ambitious with its intention to retrofit 90% of all on-road and off-road diesel engines.

Traps, behind conventional diesel engines, are soot-clogged within a very short time. The trap must therefore be frequently regenerated so that the maximum permissible backpressure is not exceeded. Regeneration is performed through combustion of the accumulated soot, which requires, under typical conditions, minimum temperature of 550°C at residual oxygen content of minimum 5%, [1]. This is usually not a problem. However, the engine exhaust gas temperatures, at the entrance to a PT, often do not attain this level or only attain it for insufficiently short periods. In these cases the regeneration of the PT would be ineffective, a fact that could lead to trap clogging and severe engine failure. Therefore, a careful selection is needed of driving routes, where vehicles equipped by PT will be driven.

VERT VERIFICATION OF THE CRT

VERT [2] is a joint project of several European environmental and occupational health agencies. The project established a trap-verification protocol that adapts industrial filtration standards [3] to include the influence of soot charge and trap regeneration phenomena. This verification test is performed for one single trap, out of a family of traps to be certified, on a representative diesel engine under all conditions expected during operation. This method of assessment lowers cost of certifying traps for large-scale retrofitting projects [1, 4]. The VERT trap verification procedure [5, 6] consists of the VERT filter test (VFT) and the VERT secondary emissions test (VSET).

<u>VFT of the HJS-CRT, [7]</u>

The test cycle used for VFT is the steady state ISO 8178 C1, where only 4 operating points at 100% / 60% speed and 100% / 50% load are used. Transient effects are investigated using free acceleration. The regeneration is controlled on the engine dynamometer by the stepwise increasing of engine load and was also confirmed in a 2000 hours field test.
The VFT procedure adds new aerosol measurement methods, e.g. SMPS, ELPI and NanoMet. These collect information on particle count efficiency, active surface and composition of the particles, and Coulometry for elemental carbon (EC)-related data.
CRT-filter reduces as usual PM emissions, but at certain operating conditions this reduction is very low and at full load operating points there is even an increase of the particle mass after the CRT. This is a common result at higher temperatures in the presence of a strong oxidation catalyst that provokes an increased production of sulfates, which pass the DPF in vapor state and condense on the PM-measuring filter. Using a CRT results in an increased share of NO_2, which is usual and characteristic for all catalytic systems. The CRT eliminates completely the black smoke during free acceleration.
Coulometry – the analysis of organic carbon (OC) and elemental carbon (EC) of the filter residuum, confirms the artefact with the sulfates condensates. Table 1 summarizes the results of coulometry and compares them with the gravimetric PM-values - all values responding to 3 min sampling time.

Table 1: Organic (OC), elemental (EC) and total (TC) carbon at 1400 rpm / full load.

[mg]	OC	EC	TC	PM	TC / PM
HJS-CRT 1400 rpm / 100 %	0.053	0.024	0.077	1.498	5.1 %
w/o trap 1400 rpm / 100 %	0.140	1.644	1.784	2.056	86.8 %

The values with the CRT correspond with usual values measured with other PT’s at the same operating point. The elemental carbon filtration efficiency (ECAG) of 98.5 % corresponds closely to the count filtration efficiency (PZAG) estimated by neglecting the spontaneous

condensates (integration range 50 – 200 nm). This result of coulometry confirms the good condition of the investigated CRT and an excellent filtration efficiency of solid particles.
The results of the VFT with HJS-CRT can be summarized as follows:

- CRT reduces the PM, but the effects of condensation at full load could overlap the gravimetric results and indicate a worse filtration efficiency.
- CRT is advantageous for all limited emissions and acts also as an oxidation catalyst.
- CRT provides an efficient filtration of nanoparticulates (99 %).
- CRT eliminates completely the visible smoke at acceleration modes.
- Regeneration of the CRT (HJS) works very well. There is no problem of backpressure increase .

<u>VSET with HJS-CRT, [8]</u>

The test cycle that is used for VSET is also ISO 8178 C1, but here all operating points are investigated. The total test duration of 200 minutes is sufficient for sampling toxic substances, which may be present in trace concentrations. In addition to the parameters from the VFT, the traces of several harmful substances (41 species here) are analyzed. These substances are:

- polychlorinated dibenzodioxins/furans (isomers) – PCDD/F (17 substances),
- polycyclic aromatic hydrocarbons - PAH (11 substances),
- nitrated polycyclic aromatic hydrocarbons - Nitro-PAH (13 substances).

To simulate a worst-case scenario, a possible de novo PCDD/F formation in the particulate trap system was forced by adding a chlorine-containing hydrocarbon to the diesel fuel and thus increasing the chlorine level in the system. Measurement results show that within the experimental uncertainty, no significant increase of the PCDD/F emissions could be detected for the investigated particulate trap system, neither with the reference fuel, nor for the chlorine containing fuel.
Figure 1 illustrates that the studied particulate trap significantly reduced the emitted PAH sum (≥ tetra-cyclic PAH) by about 98 %, compared to the corresponding basis value (w/o trap).

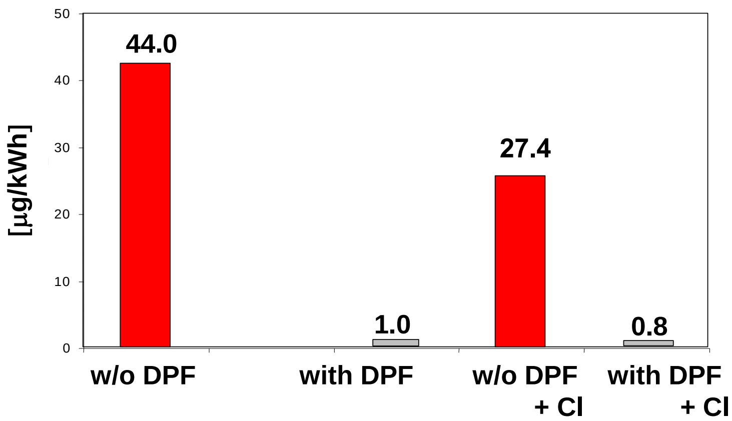

Fig. 1: Emission factors for the sum of detected PAH in µg/kWh (11 substances), HJS-CRT.

The results of the VSET with HJS-CRT show that:

- The deployment of the investigated particulate trap did not increase the PCDD/F emissions, neither with the reference fuel, nor with the chlorine added fuel.
- The applied particulate trap technology clearly reduced the emissions of carcinogenic PAH by more than 95 %. In addition, the emission rates of most Nitro-PAH

decreased, especially those of the less volatile 3-ring- and 4-ring-Nitro-PAH, when the particulate filter was applied. Also, the emission of 1-nitro-pyrene, the most prominent 4-ring-Nitro-PAH, was reduced by about 50 % when applying the trap.

- There is no break-off of Platinum from the coating of the oxidation catalyst.

The secondary emission test confirmed that the studied CRT contributes substantially to the reduction of harmful substances emissions by diesel engines.

ROAD TESTS OF URBAN BUSES IN ISRAEL

Based on VERT findings, a continuously regenerating trap manufactured by the HJS Co. was selected for retrofit installation, for the first time in Israel, on two Mercedes Benz urban buses, equipped with Euro 2 diesel engines. The type of the urban bus that was selected for tests is the most widespread model in the Israeli urban buses fleet. The CRT was installed in place of the conventional exhaust silencer.

Before installation on a bus, one new trap was tested on an engine test bench. The engine operation modes, used for the emission measurements, were selected based on the results of extensive driving behavior measurements of buses, carried out in the framework of the EU ARTEMIS Project [9]. The measured total PM mass emissions before and after the trap are presented in Figure 2. A TEOM–1105 device was used for the measurement of PM emissions.

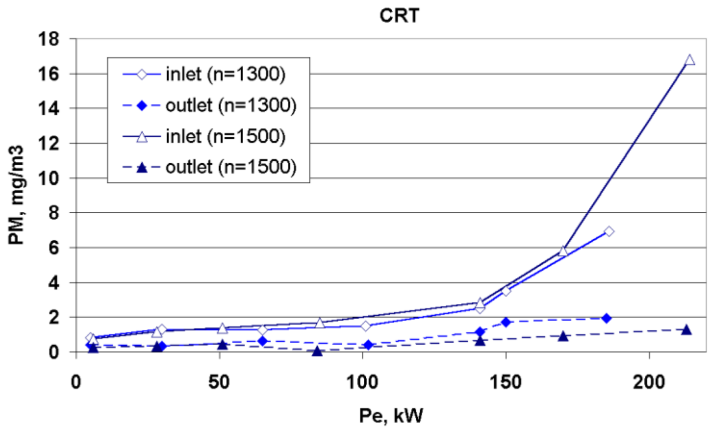

Fig. 2: PM mass emissions before and after the trap. New CRT, M-B OM-447hLA engine.

As can be seen from Figure 2, the measured data confirm earlier Swiss findings regarding the high efficiency of CRT at engine operation regimes relevant for most urban bus routes.

The buses with the CRT have accumulated, till now, about 60,000 km of traveled distance. During the tests, no registered reclamations of bus drivers or maintenance technicians have been noted. Periodic measurements of backpressure have not indicated any sensible increase of the pressure.

The road tests in Israel validated the VERT observation that the CRT eliminates completely black smoke emissions. Figure 3 illustrates it by presenting a view of the bus tailpipe with and without the CRT. As can be seen, the black soot layer was completely removed and the tailpipe was cleaned-up after approximately two weeks of driving with the CRT.

Without CRT With CRT

Fig. 3: Bus tailpipe view with and w/o the CRT.

Due to the known fact that the CRT regeneration efficiency is strongly affected by the temperature, T_e, of exhaust gases stream entering the trap, special series of experiments were carried out in order to measure T_e during real world driving of the bus on different urban routes. Significant differences in the values of T_e were observed. The lowest temperatures occur on routes where the bus operates all the time in a congested city center. Such routes could be problematical for effective operation of diesel aftertreatment devices, including CRTs. Additional problems could result from the seasonal changes in the bus engine loading. At winter period in Israel, the air conditioning system is usually not operated, a fact that leads to further reduction of the engine loads and as a result – to lower exhaust gas temperatures compared to the summer season. It was found that in the winter season, the percentage of driving time with T_e higher than 225 ^oC is about 1.7 times lower compared to summer driving, see Figure 4, [9].

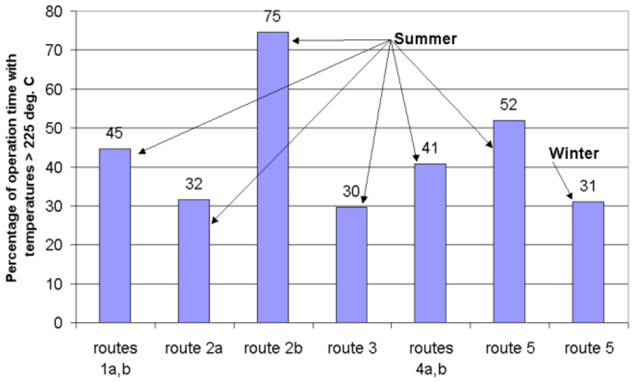

Fig. 4: Influence of bus driving pattern on exhaust gas temperature.

CONCLUSIONS

1. Selection of particulate trap type for road tests in Israel and assessment of emissions of particulates (PM) reduction potential were performed, based mainly on the results of the VERT project.
2. The results of the VERT filter test with HJS-CRT show that the CRT reduces the PM (the effects of condensation at full load could overlap the gravimetric results and simulate a worse filtration efficiency), provides an efficient filtration of nanoparticulates (99%) and eliminates completely the visible smoke at acceleration

modes. Regeneration of the CRT works very well. No problem of backpressure increase was observed.
3. The VERT Secondary Emissions Test results with HJS-CRT show that the applied particulate trap technology reduced the emissions of carcinogenic PAH by more than 95%, as well as most of Nitro-PAH, and did not increase the PCDD/F emissions.
4. Based on VERT findings, The CRT manufactured by HJS Co. was selected for retrofit installation on two urban buses in Israel. The buses with the CRT have accumulated, till now, about 60,000 km of traveled distance. During the tests, no registered reclamations of bus operators have been noted. Periodic measurements of backpressure have not indicated any sensible increase of the pressure.
5. Low temperatures of the exhaust gases were monitored on few city center routes, due to the low speed of the buses. This might pose a problem regarding the CRT regeneration in winter season, when the air conditioning system is not operated and the engine load is lower.

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