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Road Tests of Diesel Oxidation Catalysts on Urban Buses

Leonid TARTAKOVSKY, Marcel GUTMAN, Yuri ALEINIKOV, Vladimir BAYBIKOV, Mark VEINBLAT & Yoram ZVIRIN

Technion – Israel Institute of Technology, Haifa 32000, Israel

Abstract

The main objectives of the work presented here were to evaluate the possibility of reducing particulates emissions from urban buses by diesel oxidation catalytic converters in realistic Israeli driving conditions, and to evaluate their influence on bus driving behavior, performance and maintenance issues.
Two diesel oxidation catalysts (DOCs) were installed on Mercedes Benz urban buses equipped with Euro 2 generation diesel engines. These buses have accumulated, with the DOC, 100000 and 65000 km of traveled distance. The former DOC was tested in a dynamometer-engine test bench. The measured efficiency of the catalyst was in the range 0.13 - 0.61, in agreement with the manufacturer published performance data.
Keywords: *Oxidation catalyst, urban bus, particulates.*

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 of using diesel particulate traps (PT) and catalytic converters (DOC) 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. These emission targets and retrofitting projects have triggered development activities in the industry.

Several large retrofitting projects are in progress or planned worldwide, Mayer et al. (2000). 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 vehicles. The retrofitting of heavy-duty diesel engines with DOCs has been commonplace for many years on off-road vehicles used in mining, tunneling and other industrial markets, Brown & Rideout (1996).

Relative benefits of DOC technology over PT are expressed in its lower cost, no need of regeneration and, as a result – higher reliability. Of course, efficiency of particulates reduction is seriously compromised: 20-50% with DOC compared to 75-95% with a PT, Brown & Rideout (1996), Czerwinski (2000), Opris (2001).

1. Objectives

The main objectives of the work described here were to evaluate the possibility of reducing particulates emissions from urban buses by diesel oxidation catalytic converters in realistic Israeli driving conditions, and to evaluate their influence on bus driving behavior, performance and maintenance issues.

2. Methodology

The type of the urban bus that was selected for tests (Mercedes Benz O-405 with Euro 2 engine OM-447hLA) is the most widespread model in the Israeli urban bus fleets. Diesel oxidation catalysts of ACS AZ type were installed in two buses instead of the conventional bus muffler – see Figure 1.

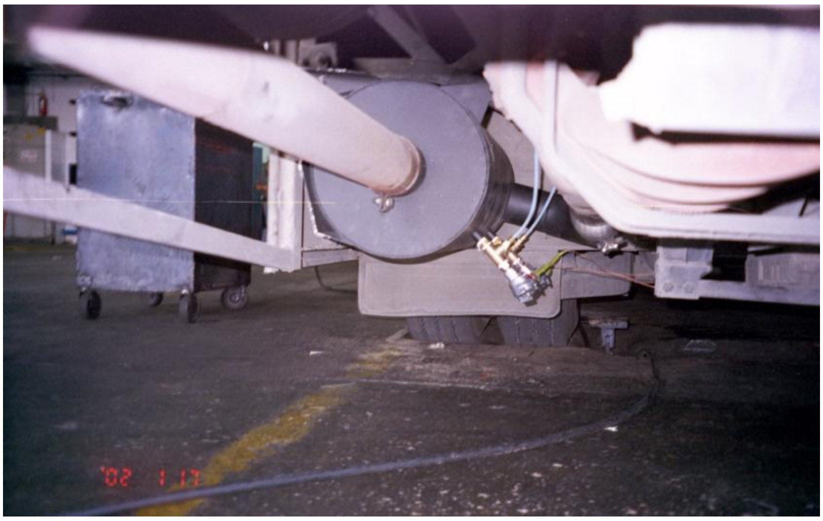

Figure 1: Oxidation catalyst installed in a Mercedes Benz O-405 bus.

The instrumented buses runs in Haifa (hilly terrain with gradients up to 12%) and in the Haifa region (flat terrain) in real-world operation. Bus routes were selected together with the bus operator (Egged) as representative for typical urban bus driving. The buses were driven by different drivers chosen by the bus operator according to its standard routine. No driving instructions were used.

Before installation on the bus, one of the new DOCs passed special series of laboratory tests, where its effects on the engine backpressure were evaluated in comparison with an appropriate new conventional bus muffler.

In order to monitor the possible DOC influence on the engine performance, the exhaust gas temperatures before and after the DOC, as well as the backpressure, were measured periodically during the whole road-testing period. Following the objective of the research, effects of the DOC on the bus engine power, operational fuel economy, driving and maintenance issues were studied. The DOC effects on the bus fuel economy were evaluated using the real world fuel consumption data that were compared with the appropriate data of this bus without the DOC at the same seasonal period. The effects of the DOC on the engine power were evaluated by measurement of the maximal power on the wheels using chassis dynamometer.

The DOC efficiency after accumulation of 100,000 km of traveled distance was evaluated by laboratory testing on a dynamometer, with an engine of the same type as installed in the bus (OM-447hLA) .In these tests, the total mass particulate emissions were measured before and after the DOC at various engine operation regimes using the TEOM particulate meter, 1105 model. After completing the laboratory tests, the DOC was returned to the bus for continuation of mileage accumulation.

Due to the known fact that DOC efficiency is strongly affected by the temperature of exhaust gases stream entering the catalyst, special series of experiments were carried out, in order to measure this temperature during real world driving of the bus (without a DOC) on different urban routes.

3. Results and Discussion

One of the DOCs that were installed on the buses passed before the installation special series of laboratory tests, where its hydraulic resistance was compared with that of a conventional new bus muffler. The tests were performed by purging cold air through the tested object. The results of these experiments are shown in Figure 2 and demonstrated lower levels of the backpressure with the DOC in the whole tested range of air flow rates. This indicates that the installation of a DOC in a bus instead of a conventional muffler would not lead to any worsening of bus engine performance.

In the framework of the study reported here, two urban buses traveled with the DOCs 100,000 and 65,000 km. During the test period, no special catalyst or catalyst related maintenance was required. No registered reclamations of the bus drivers or maintenance technicians have been noted, with the only exception of a fissure observed in one oxidation catalyst, on its exterior envelope. The reason of this malfunction was analyzed; it was fixed and was not recurred.

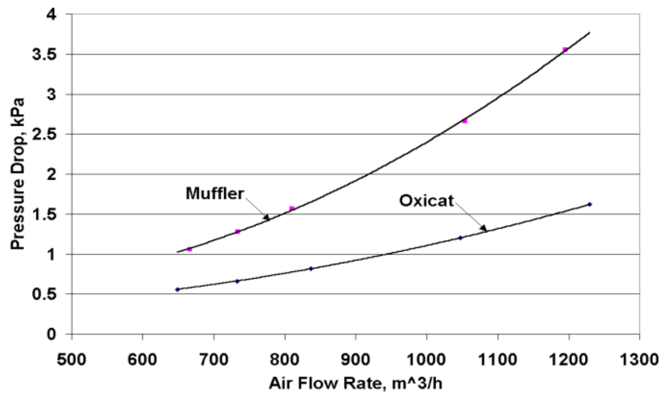

Figure 2: Comparison of a DOC with a conventional muffler – pressure drop.

Periodically (at the start, halfway and end of the test), the fuel economy data were processed and analyzed. Data on fuel consumption were supplied by the bus operator. For each analysis point, the fuel economy data during a period of a month – month and half were processed. The results were compared with the data for the same bus on the same routes, without the DOC. Figure 3 presents an example of the fuel economy data. As can be seen, no significant differences in the fuel consumption (changes in both directions) were observed after the DOC retrofitting. Periodical measurements of maximal power on the wheels gave similar results with non-significant changes in both directions. All these results lead to the conclusion that DOC retrofitting in urban buses has not led to any worsening of the bus engine performance during the test duration – 100,000 km.

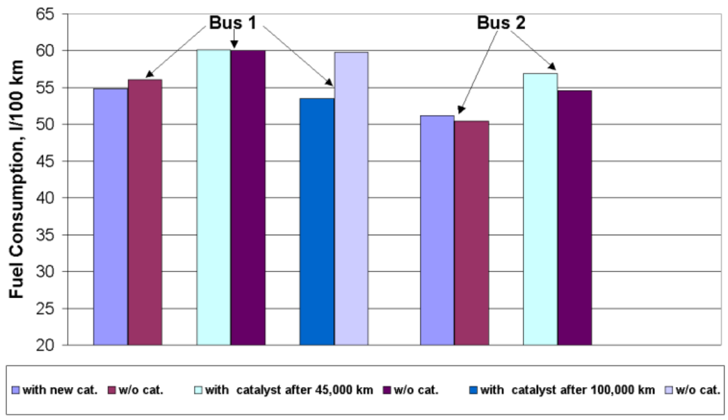

Figure 3: Effects of oxidation catalyst on bus fuel economy.

Systematical measurements of the backpressure on the two buses have demonstrated that no pressure rise was observed during the test, and the average backpressure value (excluding idling regimes) did not exceed 45 mbar. In both tested buses, similar levels of backpressure were observed.

Distribution of the exhaust gases temperatures during real world driving of the two tested buses is presented in Figure 4. The results are somewhat surprising, due to the fact that the percentage of operation with temperatures above 225 ^{o}C observed in bus No. 1, which runs on hilly Haifa routes, were lower compared to bus 2, which runs on flat routes only. A possible reason is higher driving speeds of bus 2 that was driven more time on main network roads – cf. Andre & Villanova (2002). This hypothesis is supported by the higher percentages of operation time with medium temperatures of 200 – 300 ^{o}C for bus 2. At the same time, uphill driving of bus 1 resulted in higher percentage of operation at high loads – with temperatures above 325 ^{o}C. Unfortunately, detailed description of the routes, where tested buses run, as well as speed measurements were not available in this work.

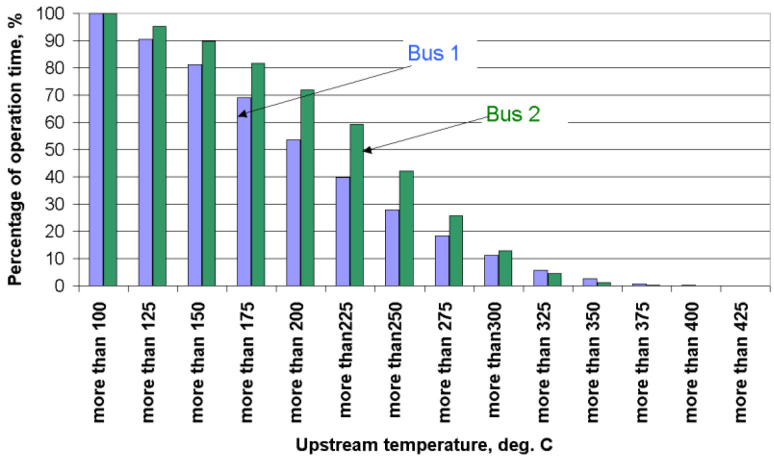

Figure 4: Exhaust gas temperatures of urban buses with DOCs.

The results of special series of experiments carried out in the framework of the ARTEMIS European Project, Tartakovsky et al. (2003), show significant differences in exhaust gases temperatures at various urban bus routes – see Figure 5. The lowest temperatures occur on routes where the bus operates all the time in a congested city center (route 3). Such routes could be problematical for effective operation of diesel oxidation catalysts (as well as other types of aftertreatment devices), because the DOC conversion efficiency would be too low. 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 – see Figure 5. It was found that in the winter season the percentage of driving time with exhaust gas temperatures higher than 225 ^{o}C is about 1.7 times lower compared to summer driving.

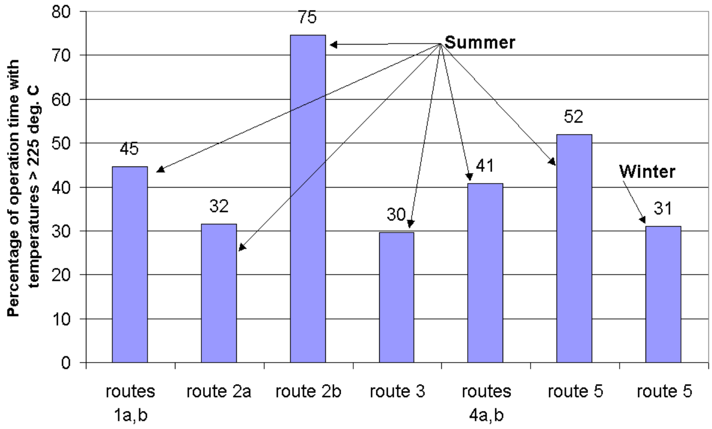

Figure 5: Influence of bus driving pattern on exhaust gas temperature, Tartakovsky et al. (2003). 1a,b – mainly flat terrain; 2a – downhill driving; 2b – uphill driving; 3 – congested city center; 4a,b – flat terrain, includes driving on main road network; 5 – only flat terrain.

The DOC that has passed 100,000 km installed on the bus was tested in the laboratory on a dynamometer test bench using an engine of the same type as that in the bus. The results presented in Figure 6 show the acceptable DOC efficiency in particulates reduction (13-61%, depending on engine operation regime) after accumulation of 100,000 km of traveled distance on the urban bus, and correspond to the published data regarding the DOC efficiency, Brown & Rideout (1996).

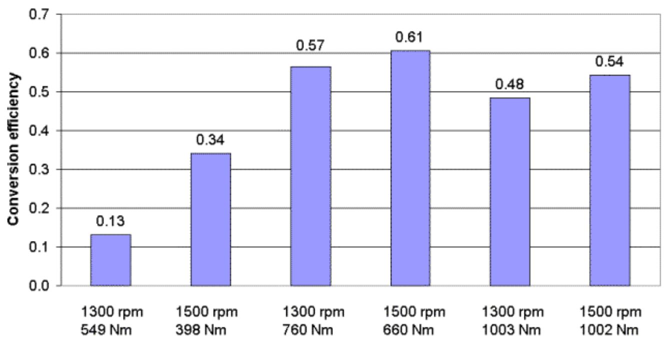

Figure 6: DOC PM conversion efficiency after 100,000 km bus driving.

Based on the available data on engine operation regimes during the urban bus driving on the same route at summer and winter seasons (route 5 on Figure 5) and DOC efficiency measurements at various engine modes, the evaluation of an average DOC efficiency at different seasons was performed. The results are presented in Figure 7. As can be seen, the DOC efficiency drops down dramatically (from 50 to 20%) in winter compared to the summer period and could achieve unacceptable low values on routes where the urban bus operates all the time in a congested city center.

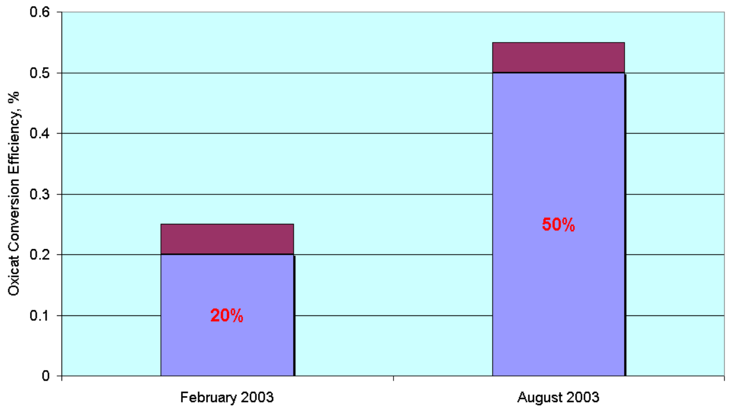

Figure 7: Season effects on DOC PM conversion efficiency.

Conclusions

In the framework of the work reported here, two urban buses traveled with the DOCs 100,000 and 65,000 km. During the test period no special catalyst or catalyst related maintenance was required. No significant differences in the buses fuel consumption were observed after the DOC retrofitting. Periodical measurements of maximal power on the wheels gave similar results. Average backpressure values during the test duration (excluding idling regimes) did not exceed 45 mbar. It has been concluded that the DOC retrofitting in urban bus does not result in any worsening of bus engine performance during the test duration – 100,000 km.

The results of laboratory tests on an engine test bench show acceptable DOC efficiency of particulates reduction (13-61%, depending on engine operation regime) after accumulation of 100,000 km of traveled distance on the urban bus, corresponding to published data regarding the DOC efficiency.

Preliminary estimate based on the results of bus driving behavior and particulate emissions measurements indicates that DOC efficiency drops down dramatically (from 50 to 20%) in winter compared to the summer period (due to low exhaust gas temperature). This could cause unacceptable low values of DOC efficiency on routes where the urban bus operates all the time in a congested city center.

Acknowledgments

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