T. ŠOLIĆ, D. MARIĆ, S. SUHI, I. SAMARDŽIĆ

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ANALYSIS OF THE VEHICLE EXHAUST SYSTEM CORROSION AND ITS EFFECT ON THE ECO-TEST RESULT

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This paper deals with analysis of the vehicle exhaust system quality and its influence on the results of measuring exhaust emissions of the Otto and Diesel motor vehicles. Results of eco-tests obtained from correct and faulty vehicle exhaust systems were compared to conclude that damages caused by corrosion had significant influence on the pass rate of vehicles at eco-test. Referring to vehicles with the Otto engine, damages in the exhaust system increase the oxygen level, which results in the increased λ factor and in failure at the eco-test. On the contrary, vehicles with the damaged Diesel engine exhaust system allow the gas to leak through the damage, so the measurement of blackening is lower, i.e. the eco-test result is better than that of the exhaust system without damage.

Key words: vehicle, exhaust system, corrosion, eco-test, technical inspection

INTRODUCTION

Combustion of fuel in a vehicle engine emits harmful exhaust gases, which were not of much concern in the past, however, the present-day rapidly growing auto industry, crises in oil derivatives supply, as well as raised awareness of environment preservation have led to the enforcement of acts and regulations related to the control and reduction of harmful exhaust gases impact on the environment and human health [1-6]. The first regulations of such kind were introduced within the Euro standards to encourage installation of catalysts in vehicles, especially of catalysts regulated by a lambda probe, i.e. an oxygen sensor [7]. Exploitation of vehicles and irregular maintenance cause damages and faults in the exhaust system, which is then functioning poorly [8]. Regular technical inspection involves control of the exhaust system quality and the composition of gases based on which results potential deficiencies may be detected [9].

EXPERIMENTAL PART

Within the eco-test performed on the Otto engine, there is the exhaust gas composition measured: CO, CO_2, NO_x, HC, O_2 and λ. Eco-test of the Diesel engine measures the blackening. With the Otto engine, the eco-test is run at higher revolution speed and then another measurement is taken in idle gear. Such measurement is performed for engines marked as REG-CAT (regulated catalytic converter), which means that they have catalytic converter and a lambda probe. Measurement in idle gear is performed for NO-CAT group of engines that do not have a catalytic converter, or that have an unregulated catalytic converter. Important values for meeting the eco-test requirements are the CO and the λ factor. If a vehicle manufacturer did not define the eco-test values, then there are legally defined values applicable. For REG-CAT engines, the following is applicable: increased revolution speed CO ≤ 0,30 %, λ = 1 (± 0,03), idle gear CO ≤ 0,50 %. For REG-CAT engines produced after the year 2003, the following is applicable: increased revolution speed CO ≤ 0,20 %, λ = 1 (± 0,03), idle gear CO ≤ 0,30 %. For NO-CAT vehicles in idle gear, the following is valid: vehicles of 1986 and older CO ≤ 4,5 %, vehicles of 1987 and younger CO ≤ 3,5 %. When performing eco-test with Diesel engines, three measurement samples are performed. A vehicle does not meet the eco-test requirements if the measured values are higher than the stipulated limit values or if 10 measurements did not result in three satisfactory measurements. There are also legally stipulated limit values for Diesel engines that have to be considered if not provided by a manufacturer: for Diesel engines without turbocharging: $k \leq 2{,}5\ m^{-1}$; for Diesel engines with turbocharging: $k \leq 3{,}0\ m^{-1}$; for Diesel engines with turbocharging after 2009: $k \leq 1{,}5\ m^{-1}$; for Diesel engines with turbocharging (Euro 6): $k \leq 0{,}70\ m^{-1}$. The Table 1 shows the vehicles with Otto, while Table 2 with Diesel engine, overviewing exhaust system faults.

The Table 3 overviews the results of eco-tests run on vehicles with Otto engine, and the Table 4 shows the eco-test results obtained on vehicles with Diesel engine.

Permeability in Otto engine negatively affects the eco-test results since it increases O_2 level. Engines with correct oxygen sensor have a higher CO level because

T. Šolić (tsolic@unisb .hr), D. Marić, I. Samardžić, Mechanical Engineerring Faculty in Slavonski Brod, University of Slavonski Brod, Croatia.
S. Suhi, Center for Vehicles of Croatia JSC, Donji Miholjac, Croatia.

Table 1 **List of vehicles with Otto engine exhibiting faults on the exhaust system**

No.	Engine	Year	Kilometers	Euro	Place of damage
1	1.1i 46 kW	2007	226000	4	near the catalyst
2	1.2i 44 kW	2003	160000	3	pipe in the middle of the vehicle
3	1.2i 48 kW	1998	330000	2	pipe before the exhaust rear pot
4	1.2i 44 kW	2002	215000	3	junction before the exhaust rear pot
5	1.4i 44 kW	1996	270000	2	after the catalyst
6	0.8 38 kW	1998	136000	3	near the exhaust rear pot
7	1.5i 65 kW	1997	250000	2	near the catalyst and exhaust rear pot
8	1.0 43 kW	2001	160000	3	near the exhaust rear pot, at the exhaust rear pot
9	1.3i 63 kW	1999	180000	3	pipe junction
10	1.2i 44 kW	1995	190000	-	pipe, exhaust rear pot
11	1.3i 55 kW	1998	330000	2	flexible pipe, near the catalyst
12	1.4i 55 kW	2002	180000	3	junction before and after the exhaust rear pot
13	1.2i 47 kW	2005	220000	4	junction before the exhaust rear pot, pipe junction
14	1.4i 50 kW	2001	230000	3	junction at the catalyst
15	0.8 37 kW	2004	110000	3	pipe junction before the exhaust rear pot

Table 2 **List of vehicles with Diesel engine exhibiting faults on the exhaust system**

No.	Engine	Year	Kilometers	Euro	Place of damage
1	1.9 SDI 50 kW	2001	222300	3	before and after the exhaust rear pot
2	1.4 HDi 50 kW	2005	280000	4	exhaust rear pot
3	1.9 TDI 66 kW	2000	369005	2	start of the pipe at the catalyst
4	1.7 TD 50 kW	1997	320000	2	near the exhaust rear pot
5	1.9 D 48 kW	1997	202000	2	exhaust middle pot, flexible pipe
6	1.4 HDI 50 kW	2004	172000	3	exhaust rear pot, pipe
7	1.9 TDI 81 kW	1997	240000	2	before the exhaust rear pot
8	2.0 HDI 66 kW	2002	360000	3	before the exhaust middle pot
9	1.6 TD 44 kW	1990	280000	-	near the catalyst, at the exhaust rear pot
10	1.9 TDI 85 kW	2002	215000	3	junction after the exhaust rear pot
11	1.9 TD	1996	300000	2	junction at the catalyst, pipe junction
12	1.9 TDI 66 kW	2003	360000	3	near the catalyst, near the exhaust rear pot
13	1.9 TDI 81 kW	1997	80000	2	exhaust middle pot, exhaust rear pot
14	1.9 SDI 50 kW	2000	250000	2	exhaust middle pot
15	1.9 D 47 kW	1996	72000	2	catalyst, exhaust rear pot

Table 3 **Results of eco-test run on vehicles with Otto engine**

REG-CAT	Before repair					
	Idle gear			Increased revolutions		
No.	CO	O_2	λ	CO	O_2	λ
1	0,83	1,27	1,040	0,90	0,89	1,035
2	>9,9	0,60	0,886	>9,9	0,55	0,850
3	0,35	9,5	1,293	0,51	8,2	1,252
4	0,02	2,55	1,220	0,10	2,30	1,190
5	0,00	1,03	1,041	0,15	0,72	1,035
6	0,00	1,3	1,080	0,00	0,70	1,040
7	0,85	6,2	1,25	1,77	1,75	0,994
8	0,02	2,0	1,060	0,00	1,25	1,048
9	0,00	0,60	1,035	0,00	0,50	1,030
10	0,20	0,66	1,010	0,17	0,50	1,004
11	0,58	0,24	0,982	2,03	0,18	0,945
12	0,04	0,70	1,037	0,00	0,48	1,023
13	0,18	1,24	1,042	0,15	1,04	1,033
14	2,44	0,10	0,952	9,99	0,05	0,843
15	0,04	0,34	1,009	0,11	0,20	0,999

Table 4 **Results of eco-test run on vehicles with Diesel engine**

Diesel	Before repair			Limit values of blackening
No.	1.	2.	3.	
1	0,11	0,06	0,22	2,00
2	0,25	0,31	0,28	1,50
3	0,12	0,09	0,15	0,70
4	0,40	0,50	0,53	2,10
5	3,05	2,89	2,95	1,82
6	4,20	4,51	4,34	1,50
7	0,69	0,98	1,14	2,00
8	1,95	1,68	2,06	2,50
9	3,62	3,80	3,54	2,00
10	3,12	2,90	3,02	2,00
11	0,98	1,04	0,85	2,00
12	0,05	0,18	0,12	2,00
13	0,89	0,95	1,04	2,30
14	0,00	0,00	0,00	2,00
15	0,60	0,68	0,51	2,30

the oxygen sensor constantly keeps the mixture in a stoichiometric ratio. Eco-test results with λ levels out of the limits can indicate the problems with oxygen sensor. Condensation of water vapor in the vehicle exhaust rear pot often causes faults in the exhaust rear pot and nearby junctions. Other faults are found at joints of various elements in the exhaust system or at pipes junctions due to structural faults that occur during welding. Such welded joint is the weakest part in a structure and it is usually the first to suffer from corrosion. In most cases, permeability in Diesel engines has a positive effect because the eco-test does not measure the incorrect composition of gases due to faults, but only the blackening of the exhaust gas. If the smoke goes out through the damage in the exhaust system, then a smaller amount of the smoke goes through the exhaust pipe into the measuring probe of the eco-test device. The Figure 1 shows locations of damages in the exhaust systems of tested vehicles.

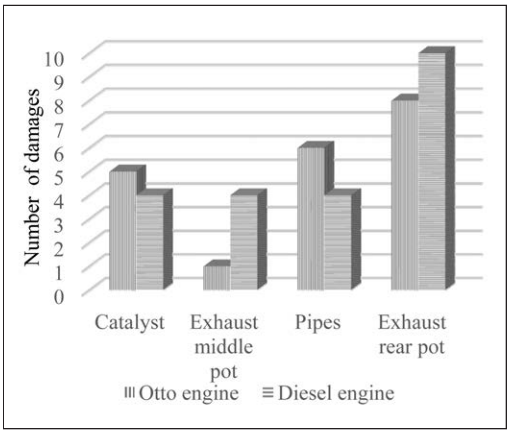

Figure 1 Locations of damages in exhaust systems of tested vehicles

Locations of damages are different if comparing the vehicles with Otto and with Diesel engines, yet the most damages are related to the exhaust rear pot in both types of vehicles, since it is a location where condensate and soot particles accumulate the most. The rest of damages is evenly distributed in Diesel engines, whereas in Otto engines, pipes and catalysts suffer more damages. This occurs because of the engine operation mode and because of the catalytic converter high temperature that damages pipes. Corrosion usually occurs on pipes because the exhaust system supporters are welded to pipes. Corrosion occurs because of defects in the structure caused by welding. The second most common cause of the exhaust system faults are pipe joints made without welding where the exhaust gases constantly come out of the exhaust system because the metal-metal joint is not sufficiently resistant to prevent leakage of exhaust gases, so there are corrosion destruction mechanisms developing consequently. The Figure 2 presents the number of tested vehicles with exhaust system faults according to the Euro standard categories.

Vehicles of the Euro 5 and Euro 6 standard are free of faults in the exhaust system. The number of vehicles in the category lower than Euro 2 is very small due to their age. Most vehicles with exhaust system faults are in the Euro 2 and Euro 3 categories, although the exhaust systems have been repaired for several times, and the faults occur on welds that are not factory-made. In vehicles with Otto engine, catalytic converter is only rarely original. The Euro 4 engines are usually at the service life point when it is time for the first replacement of the catalytic converter or other parts of the exhaust system. The Figure 3 shows the number of vehicles with Otto and Diesel engines that would fulfill the eco-test requirements before repairing of the exhaust system.

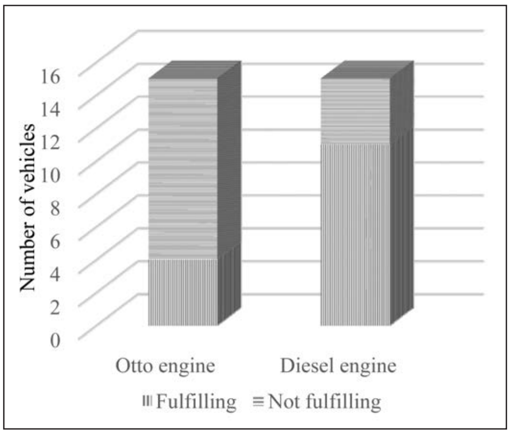

Figure 3 Vehicles with Otto and Diesel engines that would fulfill the eco-test requirements before repair

The number of vehicles that would fulfill the eco-test requirements is less than the number of vehicles with Otto engine that would not pass the eco-test. Such situation is reversed in vehicles with Diesel engine, because damages in the exhaust system have a more favorable effect on the eco-test results. The Figure 4 pre-

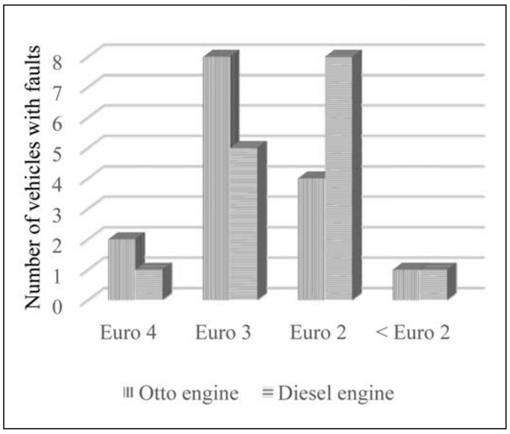

Figure 2 Vehicles with exhaust system faults according to the Euro standard categories

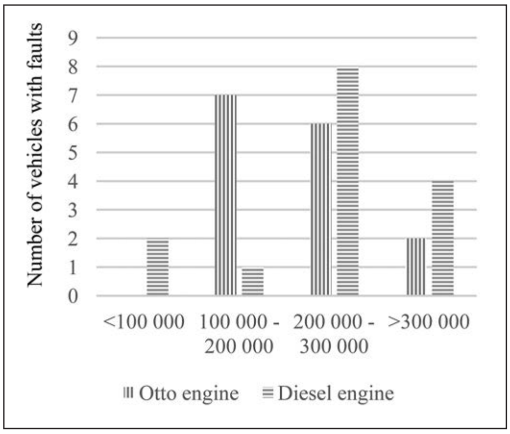

Figure 4 Number of vehicles with faults in relation to the vehicle kilometers travelled

sents the number of vehicles with faults in relation to the vehicle kilometers travelled.

According to the research results, majority of vehicles with Otto engine travel less kilometers during their service life, but factors such as vehicle standing, exposure to adverse weather conditions and exhaust gases during service still lead to more faults in the exhaust system. Illogicality with two vehicles of the Euro 2 category, older than 20 years with less than 100,000 kilometers travelled, can be explained by resetting of vehicle odometer.

CONCLUSION

Daily exploitation of vehicles causes the wear of all their parts, including parts of the exhaust system. Each product has a limited service lifespan, but the lifespan can be extended by appropriate choice of materials and by modern manufacturing processes. The exhaust system is an important part of each vehicle, yet its damages lead to engine malfunction due to pressure disturbance at the end of the exhaust pipe. Consequently, the excess oxygen is sucked into the exhaust system, more fuel is consumed and the fuel-air combustion is insufficient. Damages in the exhaust system can be detected by the eco-test. Damages in the Otto engine exhaust system are manifested by an increased oxygen level, which shows negative for the eco-test passing. However, vehicles with Diesel engines exhibit positive effects of such exhaust system damage at the eco-test. Exhaust gases go out through the damage and only a smaller amount of gas passes through the exhaust pipe, which results in less blackening. The research included all vehicles, with noticeable differences in age groups and the Euro categories, clearly detecting the group of vehicles with the most damages. The exhaust system service lifespan has increased over time, so that new vehicles are not only environmentally more friendly, but they are also more durable, since they provide longer service without any faults and damages. Modern vehicles have built-in electronic system and sensors that indicate faults and malfunctions related to engine operation, and signalize the need for preventive maintenance.

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Responsible person for English translation is prof. Martina Šuto, University of Osijek