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Evaluation of the effectiveness of replacement catalytic converters

Abstract: The article reviews the market for replacement catalytic converters and discusses the results of comparative studies of catalytic converters: the original and the replacement. There were presented the exemplary results of emissions from vehicles exhaust system, equipped with a spark-ignition engine equipped with new catalytic converters: original and replacement. The estimation of fulfillment by replacement catalytic converters of the 103 UNECE Regulations requirements were made with an estimate of the potential impact of the use of replacement catalytic converters upon emission factors.

Key words: *catalytic converters, exhaust emission, emission factors, replacement parts*

Ocena skuteczności zamiennych reaktorów katalitycznych

Streszczenie: W artykule dokonano przeglądu rynku zamiennych reaktorów katalitycznych oraz omówiono wyniki badań porównawczych reaktorów katalitycznych: oryginalnego i zamiennego. Przedstawione zostały przykładowe wyniki badań emisji zanieczyszczeń z układu wydechowego samochodu wyposażonego w silnik z zapłonem iskrowym wyposażonego w nowe reaktory katalityczne: oryginalny oraz zamienny. Dokonano oceny spełniania przez badane zamienne reaktory katalityczne wymagań regulaminu 103 EKG ONZ wraz z oszacowaniem potencjalnego wpływu stosowania zamiennych reaktorów katalitycznych na wskaźniki emisji.

Słowa kluczowe: *reaktory katalityczne, emisja zanieczyszczeń, wskaźniki emisji, części zamienne*

1. Introduction

Poland has adopted provisions concerning emission control devices and intended for replacement parts (UNECE Regulations 103 [1], Council Regulation 715/2007 [2]), but there are no mechanisms in the country, which allow to control the fulfilment of these requirements. The experiment collected during the homologation tests of gas systems adjusting vehicles to power the engines with propane-butane shows significant differences in efficacy of replacement catalytic converters in relation to the original converters. Therefore, there is a need to examine the performance and durability of the replacement pollution control device, especially catalytic converters, and the evaluation of the potential effects of the absence of such control mechanisms.

2. Market regulations for replacement pollution control devices

In countries which have signed an agreement on mutual recognition of certificates of approval of pollution control devices, which are intended for the replacement, undergoes, before the introduction of the market, to approval tests in accordance with:

- UNECE Regulation 103 or Council Regulation 715/2007, as amended in the case of motor vehicles categories, which are tested for emissions by UNECE Regulations 83 [3];
- Annex 13 to UNECE Regulations 49, series of amendments 06 [4] in case of motor vehicles with category, which are subject to tests according to UNECE Regulations 49 in terms of emissions.

These regulations specify requirements that the devices have to meet and test methods for check of these requirements fulfilment. They will be discussed on the example of the UNECE Regulations 103.

In the UNECE Regulations 103 is given definition of type of pollution control device. According to this definition, to the same type of pollution control device, which can either be catalytic converter and particle filter device are no differ from each other in the aspect of the following parameters:

- number of coated substrates, structure and material,
- type of catalytic activity of each substrate,
- volume, ratio of frontal area and substrate length,
- catalyst material content,
- catalyst material ratio,
- cell density,
- dimensions and shape,
- thermal protection.

Approval of a replacement catalytic converter means the approval of a converter intended to be fitted as a replacement part on one or more specific types of vehicles with regard to:

- the limitation of pollutant emissions,
- noise level,
- effect on vehicle performance,
- on the on-board diagnostic (OBD),
- durability.

General requirements

Apart from specific requirements concerning emission of pollutants from the exhaust system, noise level, vehicle performance or OBD performance, section 5.1 of UNECE Regulations 103 stipulates also general requirements:

- the installation of the replacement catalytic converter shall be at the exact position of the original catalytic converter;
- the position on the exhaust line of the oxygen probe(s) and other sensors, if applicable, shall not be modified;
- if the original catalytic converter includes thermal protections, the replacement catalytic converter shall include equivalent protections;
- the replacement catalytic converter shall be durable, that is designed, constructed and capable of being mounted so that reasonable resistance to the corrosion and oxidation phenomena to which it is exposed is obtained, having regard to the conditions of use of the vehicle.

Requirements regarding emissions

The evaluation comprises a comparison of emission of pollutants from the exhaust system of a vehicle equipped with an pollution control device intended for replacement parts and original device. Every device is subject to three measurements of emission of pollutants from the exhaust system in accordance with UNECE Regulations 83. The requirements regarding emissions of the vehicle equipped with the replacement catalytic converter shall be deemed to be fulfilled if the results meet for each regulated pollutant the following conditions:

$$M \le 0.85 \cdot S + 0.4 \cdot G, \quad (1)$$

$$M \le G \quad (2)$$

where:

M – mean value of the emissions of one pollutant (CO, THC, NMHC, NO_x, PM, PN) or the sum of two pollutants (THC + NO_x) obtained from the three type I tests with the **replacement** catalytic converter;

S – mean value of the emissions of one pollutant (CO, THC, NMHC, NO_x, PM, PN) or the sum of two pollutants (THC + NO_x) obtained from the three type I tests with the **original** catalytic converter;

G – limit value of the emissions of one pollutant (CO, THC, NMHC, NO_x, PM, PN) or the sum of two pollutants (THC + NO_x) according to the type approval of the vehicle(s) divided by - if applicable - the deterioration factors determined in accordance with paragraph 5.4 of UNECE Regulations N^o 103.

Where approval is applied for different types of vehicles from the same car manufacturer, and provided that these different types of vehicles are fitted with the same type of original catalytic converter, the type I testing may be limited to at least two vehicles selected after agreement with the technical service responsible for approval.

Requirements regarding OBD system

Requirements regarding the compliance of OBD system relate only to those pollution control devices the effectiveness of which is monitored by OBD system. Compliance with OBD system of the replacement pollution control device is verified in accordance with the procedures laid down in Appendix 1 to Annex 11 of UNECE Regulations 83, series of amendments 05 or 06 (depending on which amendment was in force at the time of homologation tests regarding vehicle for which the tested device was intended).

All other components of the tested vehicle monitored by OBD system should be properly fitted and in operating condition. To examine the said requirement, emission tests can be applied using the original pollution control device fitted. If during such tests the MI lamp does not beam, it means that all elements of the tested vehicle are working properly.

A replacement pollution control device is considered to fulfil requirements as regards compliance with OBD system if:

- during emission tests with a replacement pollution control device installed the MI lamp does not light;
- upon fitting of the replacement pollution control device with worsened operability (damaged) the MI lamp beams in accordance with the requirements of the UNECE Regulations 83 (having exceeding the limit values); for vehicles equipped with spark-ignition engines if the total emission of THC and NMHC measured for a vehicle equipped with a replacement pollution control device is greater than the emission of those pollutants measured in a vehicle equipped with an original pollution control device, limit values of THC and NMHC are increased by the difference of emissions measured with the replacement and original pollution control device.

Requirements regarding vehicle performance

To establish whether a replacement pollution control device fitted in the exhaust system does not affect the vehicle performance, measurements of the exhaust back-pressure are made. The value of the back-pressure should not be greater than the maximum permissible value allowed by the producer of the engine.

Admissible is also an alternative method whereby the maximum power absorbed on engine test bed is measured at the speed corresponding to the engine rated speed. The power thus measured for the vehicle equipped with a replacement pollution control device cannot be lower by more than 5% from the value measured for the original device.

Requirements regarding durability of the pollution control device

The replacement pollution control device must meet requirements set forth in section 5.3.6 of UNECE Regulations 83, i.e. the weighted mean of emission of pollutants from the exhaust system multiplied by emission deterioration factors should be lower or equal to the emissions limit for every pollutant. The deterioration factors ought to be determined based on durability tests conducted according to V type tests in the UNECE Regulations 83 or adopted according to those specified in respective versions of the rules.

Requirements regarding systems subject to periodical regeneration

In case of replacement systems, which require periodical regeneration, tests should be conducted in order to verify the fulfilment of requirements as regards pollutant emissions, vehicle performance, durability and OBD system as described above. Measurements of pollutant emissions from the exhaust system must be made in accordance with section 3 of Annex 13 to UNECE Regulations 83.

In addition, for the replacement system requiring periodical regeneration, D ratio should be determined.

3. Replacement catalytic converters market overview

Replacement catalytic converters offered by the producers can be classified into two groups:

- universal,
- dedicated to a particular type of vehicle.

In the group of universal catalytic converters there are catalytic converters intended for vehicles meeting a particular emission level (up to Euro 2, Euro 3 or Euro 4) and for a particular engine displacement, e.g. catalytic converter for Euro 3 vehicles with engine displacement up to 1200 cm^3.

In order to fulfil stricter and stricter requirements regarding the emission of pollutants from the exhaust system, vehicle producers began to fit catalytic converters closer to the exhaust manifold, whereupon the converters achieve full operability earlier. At present (from vehicles fulfilling Euro 4 standard) solutions are frequent where the exhaust manifold and catalytic converter form one element. Those comprise the second group of replacement converters, dedicated to a particular car model.

In Poland catalytic converters are supplied by producers listed in Table 1.

Table 1. Producers of replacement catalytic converters offered on Polish market

Producer	Country of origin
BM Catalysts	UK
Bosal Holding	The Netherlands
AS, SL	Spain
Lindo-Gobex	Poland
PPH JMJ	Poland
AWG-Polonez	Poland
Magnaflow	USA

Table 2 presents prices of original and replacement catalytic converters offered on the Polish market for the most popular types of vehicles.

Table 2 Prices [expressed in PLN] of new catalytic converters offered on the domestic market for chosen types of vehicles

Vehicle	Original	Replacement	
		Min.	Max.
Fiat Panda 1.2 8V	2580	500	1500
Skoda Fabia 1.2	2500	700	1050
VW Passat IV 1.6i 8V	3800	235	865
Toyota Corolla 1.6 16V	3300	315	1190
VW Golf IV 1.6i 16V	3500	430	1150

When analysing the prices it is apparent that there is both a considerable difference in the price of the original catalytic converter vs. the price of the replacement converters as well as a significant variety of prices of replacement catalytic converters intended for the same type of vehicle.

This substantial span of prices gives rise to a question whether the effectiveness and durability of replacement catalytic converters is close to the effectiveness and durability of original converters. For this purpose, comparability tests of pollutant emissions from the exhaust system of the original and replacement catalytic converters were conducted.

4. The object and methodology of tests

The tests of emission were performed at FIAT Panda 1.2 complying Euro 3 limit (Fig. 1). Its basic data are presented in Table 3.

Table 3. Basic data for FIAT Panda 1.2

Make	FIAT
Model	Panda 1.2
Capacity	1242 cm^3
Power output	44 kW
Category	M1
Emission level	R83.05A (EURO 3)
Millage	101 500 km

Fig. 1. Tested FIAT Panda 1.2 on engine test bed

The tested vehicle was equipped with a single catalytic converter integrated with an exhaust manifold (Fig. 2).

Fig. 2. Replacement catalytic converter for FIAT Panda 1.2

The pollutant emissions from the exhaust system were examined in test type I of UNECE Regulations 83. The tests were carried out in two thermal conditions of the engine:

- a vehicle conditioned for minimum 10 hours at the ambient temperature of 23÷26°C, tests of emission upon start-up of a cold engine;
- engine and catalytic converter fully warmed up.

Two catalytic converters were subject to the tests of pollutant emissions: the original and replacement converter. As the replacement catalytic converter served chosen was the most cost-effective available on the market. Both converters were new. The converters were prepared for the tests according to the requirements set forth in UNECE Regulations 103, i.e. after they had been fitted in the vehicle and prior to the start of the emission tests, the extra-urban cycle of type I test was repeated 12 times.

5. Results of testing

In order to establish whether the tested vehicle equipped with a new catalytic converter fulfils the requirements of Euro 3 level as regards the pollutant emissions from the exhaust system, emission was evaluated in type I test (upon start-up of a cold engine). Fig. 3 presents pollutant emissions from the exhaust system in type I test (upon start-up of a cold engine) for catalytic converters: original and replacement expressed as a percentage of the admissible value.

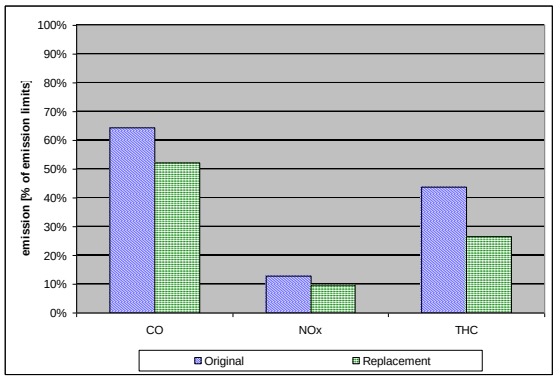

Fig. 3. Pollutant emissions from the exhaust system in type I test (after start-up of a cold engine) for catalytic converters: original and replacement, expressed as % of the admissible value

In case of a replacement catalytic converter the result represents a mean of four measurements, whereas for the original converter the result represents only one measurement. During the tests due to temperatures in the engine chamber the plastic intake manifold had deformed and false air began to move towards the inlet system, thus causing uneven operation on idle and increasing considerably the emission of nitrogen oxides. Measurements of the original converter were interrupted and shall be continued after the failure is repaired. Nevertheless, it can be stated that for both tested catalytic converters the vehicle satisfies the requirements of Euro 3 level as regards pollutant emissions from the exhaust system. Moreover, emission measured for a car equipped with a replacement catalytic converter is slightly lower vs. emission measured for the original converter. Differences for CO and NO_x fall within the limits of measurement uncertainty, whereas in case of THC the difference is greater than measurement uncertainty.

To compare the effectiveness of operation of both tested catalytic converters a series of measurements of pollutant emissions were conducted via type I test upon start-up of a fully warmed up engine. For a vehicle with a replacement converter, 8 measurements were performed, whereas for the vehicle fitted with an original converter – only one measurement (for the same reasons as regards the measurement of emissions upon start-up of a cold engine).

Fig. 4 presents results of emission tests. With regard to the replacement converter, the value presented in the chart represents a mean of 8 measurements.

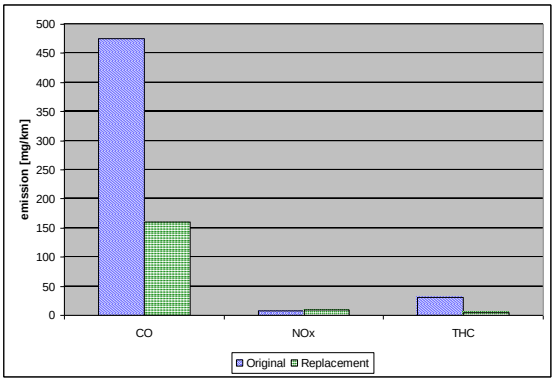

Fig. 4. Pollutant emissions from the exhaust system in type I tests (after start-up of a fully warmed engine) for catalytic converters: original and replacement

Fig. 5 presents average, minimum and maximum value of pollutant emissions from the exhaust system measured for a car with a replacement catalytic converter and emission for a car with an original catalytic converter. The minimum and maximum value was calculated as an average value decreased or increased by 3-times the value of standard variance computed based on results of a series of 8 measurements.

Based on the results, it may be concluded that after being fully warmed up a replacement catalytic converter characterises with greater effectiveness in relation to carbon oxide and hydrocarbons, whereas as regards nitrogen oxides the effectiveness of operation of both converters is similar.

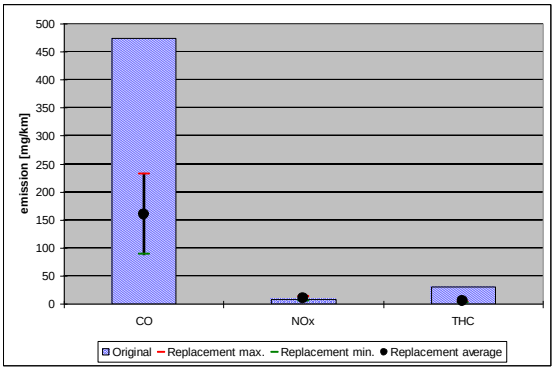

Fig. 5. Pollutant emissions from the exhaust system in type I tests (after start-up of a fully warmed engine) for catalytic converters: original and replacement

6. Conclusions

The tested vehicle with a replacement catalytic converter proved in type I test slightly lower pollutant emissions from the exhaust system compared to the vehicle with an original catalytic converter. Differences for CO and NO_x ranged within the limits of measurement uncertainty, while as regards THC such difference was greater than measurement uncertainty. Based on the results of tests it can be stated that both converters in new condition featured similar effectiveness as regards emissions following start-up of a cold engine. Once the engine and catalytic converter were warmed up fully the effectiveness of the replacement catalytic converter for CO and THC was greater than that of the original converter, while in case of NO_x the effectiveness of both converters was similar.

Both tested catalytic converters were new. There are plans to conduct performance tests with those converters to evaluate their durability and effectiveness of operation in true conditions of use.

The tested replacement catalytic converter is classified in the group of converters dedicated to a particular car model. In producing this type of replacement converters, the same quantity of precious metals can be applied as in the original converter. For this reason it is easier to achieve similar effectiveness of such replacement converter.

In order to evaluate the effectiveness and durability of universal catalytic converters there are plans to conduct tests of a vehicle fulfilling requirements of Euro 1 / Euro 2 emission levels, for which a universal replacement converter shall be acquired.

Nomenclature/*Skróty i oznaczenia*

OBD On-board diagnostic / *system diagnostyki pokładowej*
LPG Liquified Petrolum Gas / *gaz skroplony*
CO carbon oxide/ *tlenek węgla*
THC sum of hydrocarbon expressed in C_1 concentration / *suma węglowodorów w przeliczeniu na stężenie C_1*
NO_x NO and NO_2 / *suma NO i NO_2*
UNECE United Nations Economic Commission for Europe /*Europejska Komisja Gospodarcza*
NMHC non methane hydrocarbons / *węglowodory niemetanowe*
PM particulates matter / *masa cząstek stałych*
PN particulates number / *liczba cząstek stałych*

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