THE INFLUENCE OF EXHAUST CATALYST WITH REDUCED EFFICIENCY ON REAL EXHAUST EMISSIONS

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Abstract
The aim of the paper is to assess the real emission production of passenger car with high mileage. The car was suspected of a reduction of catalyst's efficiency (stored fault in OBD system). Experiments were carried out with a usage of the idle emission test and methodology similar to homologation process under homologation cycle NEDC. The results prove that the idle test is not able to detect lower catalyst's efficiency while the NEDC cycle results show even 5-times increase of emission production.

Key words: idle test, homologation cycle, NEDC, chassis dynamometer.

INTRODUCTION

The introduction of the widely known three-way catalytic (TWC) converter in the early 80's, which effectively removes CO, unburned HCs and NOx emissions, in stoichiometrically operated gasoline vehicles has proven to be an efficient technique to meet the ever more stringent emission limits BIRGERSSON (2006). The catalyst uses a ceramic or metallic substrate with an active coating incorporating alumina, ceria and other oxides and combinations of the precious metals - platinum, palladium and rhodium. By the highly porous structure and resulting large surface area for the noble metal phase is ensured the high catalyst efficiency. The catalyst requires the operating temperature around 400 – 800 °C, that might be a problem especially during cold starts. Therefore, the close-coupled catalyst (CCC) placed very near to engine is mainly used for reducing the cold start emissions JIA (2008). According to *EU DIRECTIVE 70/220/EEC* the catalyst durability must be minimally by 160 000 km.

The aim of planned experiments was to compare results of 2 different emission tests conducted on original CCC with high mileage and on the new one and confirm or disprove the fault stored in the OBD system.

MATERIALS AND METHODS

The vehicle Skoda Fabia combi first generation with 1.2 litre spark engine was used for this experiment. Detailed technical specification is summarized in Tab. 1. The fault in a form: "low catalyst efficiency" was saved in on-board diagnostic system (OBD).

The catalyst's efficiency will be tested using two different methodologies. At the first the vehicle will be tested by the methodology of regular emission test in the Czech Republic. There are the idle emission tests, when the vehicles engine is tested at idle and raised idling speed. The Tab. 2 show the maximum limits for this vehicle.

At the second the car will be tested with usage of methodology similar to homologation process. The vehicle will be driven according to the homologation cycle NEDC (New European Driving Cycle) and total emission production will be evaluated. The vehicle should fulfil the EURO-4 limits which are showed in the Tab. 3.

After completing the above tests the replacement of the catalyst for a new will be conducted and then the testing methodology will be repeated with using a new catalyst.

VMK emission analyser was used for emission measurement on the chassis dynamometer. Standard analyser ATAL AT505 was used for the regular inspection of emission measurement. Both analysers use non-dispersive infrared (NDIR) method to detect CO, CO_2, and HC emissions and electrochemical cell to O_2 and NO_X emissions. Data was recorded with 1 Hz frequency on memory card (VMK) and on hard disk in case of the Atal analyser. The technical data of analysers are summarized in Tab. 4 and 5.

Tab. 1. – Vehicle technical specification

Vehicle	Skoda Fabia 1.2 HTP
Manufacture year	2004
Mileage	202, 000 km
COMBUSTION ENGINE	
Design	spark ignition, atmospheric
Number of cylinders and valves	3 in row, 12 valves
Fuel	gasoline
Volume of cylinders	1198 ccm
Power	47 kW at 5400 rpm
Torque	112 Nm at 3000 rpm
CO_2 emission	140 $g \cdot km^{-1}$
EU limit	EU4
CAR BODY	
Service weight	1250 kg
Total weight	1750 kg
DRIVE PERFORMANCE	
Max. speed	162 $km \cdot h^{-1}$
Acceleration (0-100 $km \cdot h^{-1}$)	16.3 s
Fuel consumption	7.7 / 5.1 / 6 litre/100 km

Tab. 2. – Maximal emission limits for tested vehicle at the idle tests

regime	engine speed min^{-1}	CO %	CO_2 %	HC ppm	NO_X ppm	Lambda -
idle	600-800	0.5	-	300	-	-
raised idling	2400-2600	0.3	-	300	-	0.97-1.03

Tab. 3. – Maximal emission limits for tested vehicle at the homologation tests

Stage	Date	CO	HC	NOx
		$g \cdot km^{-1}$		
Euro 4	2005.01	1.0	0.1	0.08

Tab. 4. – Technical parameters of VMK emission analyser

Measured values	Measurement range	Resolution	Accuracy
CO	0 ... 10 % Vol.	0.001 % Vol.	0 … 0.67%: 0.02% absolute, 0.67% … 10%: 3% of measured value
CO_2	0 ... 16 % Vol.	0.01 % Vol.	0 … 10%: 0.3% absolute, 10 … 16%: 3% m.v.
HC	0 ... 20 000 ppm	1 ppm	10 ppm or 5% m.v.
NO_X	0 ...5 000 ppm	1 ppm	0 … 1000 ppm: 25 ppm, 1000 … 4000 ppm: 4% m.v.
O_2	0 ... 22 % Vol.	0.1 % Vol.	0 … 3%: 0.1%, 3 … 21%: 3%

Tab. 5. – Technical parameters of Atal emission analyser

Measured values	Measurement range	Resolution	Accuracy
CO	0 ... 10 % Vol.	0.01 % Vol.	0.03 % Vol or 5 % of measured value
CO_2	0 ... 20 % Vol.	0.1 % Vol.	0 … 10%: 0.3% absolute, 10 … 16%: 3% m.v.
HC	0 ... 2 000 ppm Vol.	0.01 % Vol.	0.1 % Vol. or 5 % m.v.
	2001 … 9000 ppm Vol.	10 ppm Vol.	5 % of m.v.
NO_X	0 ...5 000 ppm	1 ppm Vol.	1 ppm Vol.
O_2	0 ... 4 % Vol.	0.01 % Vol.	0.01 % Vol.
	4 ... 21 % Vol.	0.1 % Vol.	5 % of m.v.

The car diagnostic system VAG-COM was used for communication with ECU for obtaining immediate values of the engine operational parameters (revolutions, engine load, MAF, IAT, etc.). These values were used for calculating weight emission production in (g·s^{-1}) using method described by SAINI ET AL. (2013) as shown in Eq. (1):

$$E_{(g \cdot s^{-1})} = \frac{\left(\left(M_{af} + F_f\right) \cdot M_Q \cdot Q\right)}{M_{exh}} \tag{1}$$

where $E_{(g \cdot s^{-1})}$ is the emission rate in (g·s^{-1}), F_f is the instantaneous fuel flow rate in (g·s^{-1}), M_Q is the molecular weight of the exhaust gases (g·mol^{-1}), Q the fraction of exhaust gases (%), M_{af} is the mass air flow (g·s^{-1}) and M_{exh} is the exhaust molar mass (g·mol^{-1}).

Fig. 1. – The experiment setup

RESULTS AND DISCUSSION

At first the idle emission measuring was performed. In the Tab. 6 are results of idle test for both catalysts. There is evident that original catalyst fulfils all required limits but the new one reaches significantly better values (especially in case of CO emissions). These simple tests led to suspect for the lower efficiency of original catalyst.

Tab. 6. – The results of idle tests for both catalysts.

	Speed	CO	CO_2	HC	NO_X	Lambda
	min^{-1}	%	%	ppm	ppm	-
original	740	0.22	14.7	3	6	0.999
catalyst	2560	0.1	15.1	2	5	0.998
new	730	0.01	15	5	0	0.999
catalyst	2520	0.02	14.9	6	4	0.999

Secondly tests on the chassis dynamometer were conducted with the aim to engine's operating under higher load in comparison with idle tests. On the fig. 2 are shown the immediate values of CO emissions production for both catalysts in the EUDC (Extra Urban Driving Cycle), which is the second part of NEDC cycle. The engine is more loaded at the moment and the effect of worse catalyst efficiency is more evident. As can be seen from fig. 2, in this case original catalyst during intensified acceleration was followed by an increased production of CO. The suspect of lower catalyst efficiency has been confirmed by summary results for whole NEDC cycle.

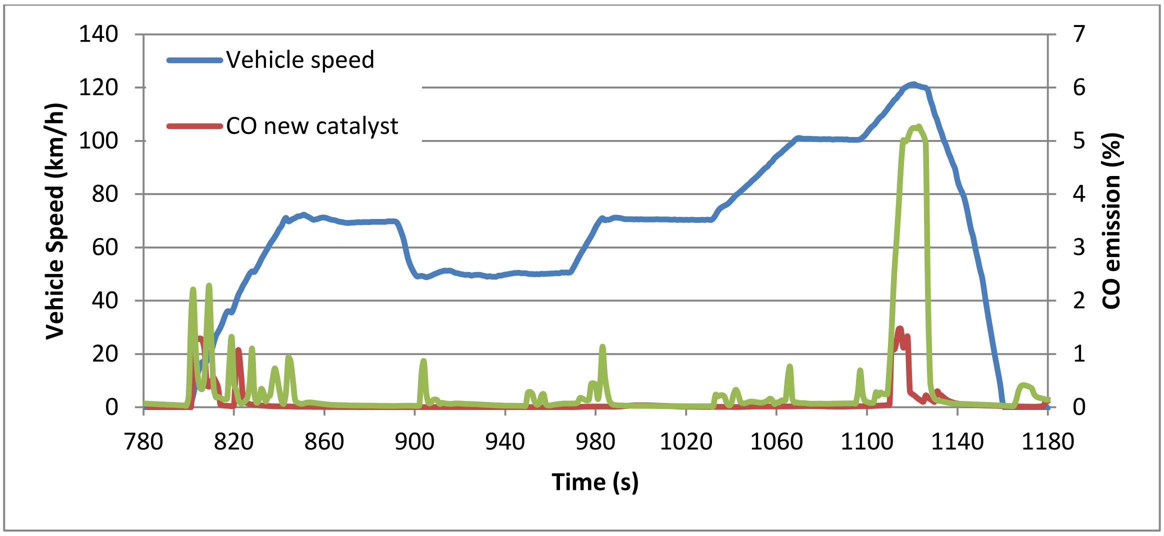

Fig. 2. – Immediate values of CO emissions for both catalysts in the EUDC cycle.

Tab. 7. – The results of NEDC tests for both catalysts

	Distance	CO	CO_2	NO	HC
	km	$g \cdot km^{-1}$	$g \cdot km^{-1}$	$g \cdot km^{-1}$	$g \cdot km^{-1}$
original catalyst	10.92	3.82	171	0.28	0.01
new catalyst	10.95	0.71	178	0.07	0.005
directive EU4 and manufacturer data	10.93	1.00	140	0.08	0.1

In the Tab. 7 are summarized results of all emission production in the NEDC cycle.

From the Tab. 7 is evident that the CO and NO emissions of original catalyst exceeded many times the limits for EU4 standard, while the HC emissions are reduced sufficiently. Slightly increased CO_2 emissions may be caused by using winter tyres. The original catalyst's poor results were probably caused by its ending durability due to high mileage of tested car. As was mentioned above, according to EU directive 70/220/EEC the catalyst durability must be minimally 160 000 km. On the other hand, the reason for these results could be caused by the aging phenomena of catalyst. There are many distinct types of catalyst deactivation. As is reported by BARTHOLOMEW (2001) they can be classified into six distinct types: (i) poisoning, (ii) fouling, (iii) thermal degradation, (iv) vapour compound formation accompanied by transport, (v) vapour-solid and/or solid-solid reactions, and (vi) attrition/crushing. Especially on the tested car is well known problem with the catalyst overheating due to the placement of the catalyst direct behind the exhaust pipe and very close to the engine block. WINKLER ET AL. (2001) concluded that the thermal degradation has a major impact to the reduction of catalyst efficiency.

CONCLUSIONS

The aim of the paper was to compare results of 2 different emission tests conducted on original CCC with high mileage and on the new one and confirm or disprove the fault stored in the OBD system. Although the tested car passed the standard idle emission test for regular checks, by testing under real engine loading test (similar to the homologation process) it is evident significant increase in emission production. Especially in items as CO and NO, production was achieved 4 times higher than permitted by the EU4 directive. According to the results the fault stored in the OBD system was confirmed. Regardless to very often criticism linked with homologation cycles that they are not representative for real-world vehicles' usage. On the hand the use of idle test as a methodology for regular emission checks proves to be insufficient. As is seen from Tab. 7, after replacing the catalyst all emission limits has been fulfilled.

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REFERENCES

1. BARTHOLOMEW, C., H.: Mechanisms of catalyst deactivation, Applied Catalysis A: General, 212, 2001, 17–60.
2. BIRGERSSON, H., BOUTONNET, M., KLINGSTEDT, F., MURZIN Y. D., STEFANOV, P., NAYDENOV, A.: An investigation of a new regeneration method of commercial aged three-way catalysts, Applied Catalysis B: Environmental 65, 2006, 93–100.
3. EUROPEAN DIRECTIVE 70/220/EC.
4. JIA L., SHEN, M., WANG, J., WANG, J., CHU, X., GU, W.: Durability of three-way and close-coupled catalysts for Euro IV regulation, JOURNAL OF RARE EARTHS, Vol. 26, No. 6, 2008, p. 827.
5. SAINI, B., VERMA, R., HIMANSHU, S., GUPTA, S.: Analysis of exhaust emissions from gasoline powered vehicles in a sub-urban Indian town, International Research Journal of Environment Sciences, 2 (1), 2013, 37–42.
6. WINKLER, A., FERRI, D., HAUERT, R.: Influence of aging effects on the conversion efficiency of automotive exhaust gas catalysts, Catalysis Today 155, 2010, 140–146.

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